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Cover: The short-tailed Mouse, *Leggadina lakedownensis*.

Illustration by Jill Ruse.

New species and records of Phreodrilidae (Annelida: Clitellata) from Western Australia

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Abstract – Two new species of Phreodrilidae are described from habitats and regions of Western Australia from which the family has not previously been recorded. *Phreodrilus peniculus* sp. nov., the first phreodrilid to be described from north-western Australia, is characterised by a very short pseudopenis terminating in a small papilla at the apex of a long invagination of the body wall. This and other *Phreodrilus* with coiled pseudopenes are shown to have the pseudopenes and sometimes part of the atria ciliated. *Astacopsidrilus edwardi* sp. nov., which inhabits temporary seepages on granite outcrops of the inland south-west, has a swelling on the spermathecal ducts and often has replicated spermathecal chaetae. Additional records are provided for some previously recorded species.

Keywords: Phreodrilidae, oligochaetes, springs, Pilbara region, granite outcrops, new species

INTRODUCTION

Until recently, the only phreodrilid recorded from Western Australia was *Astacopsidrilus novus* Jackson, 1931, which is still known only from Lesmurdie Falls near Perth (Jackson, 1931). Pinder and Brinkhurst (1997) listed eight additional species, including three original species descriptions, notes on three undescribed species and records of two species also known from south-eastern Australia. These species are all from the near-coastal regions of south-western Australia, mostly from the high rainfall Warren bioregion. The present paper describes two additional species: one known only from temporary seepages on granite outcrops in the central wheatbelt and goldfields and one from springs in the Pilbara region. Additional records of some previously described species are also provided.

METHODS

Specimens of *P. peniculus* were collected using a D frame sweep net and specimens removed from the sample in the field (Halse *et al.*, in press), while *A. edwardi* were hand-picked from beneath moss beds on granite outcrops. Specimens of both species were killed and preserved in 70% ethanol. Examined material is deposited with the Western Australian Museum (WAM), or retained by the author (AP collection).

SYSTEMATICS

Phreodrilus peniculus sp. nov.
Figures 1A,C and 2A

Material examined

Holotype

Flowing water in reach with predominantly fine sediments, downstream of Warrie Springs in upper tributary of Shaw River, 22°15'36"S 119°42'21"E, 8 Sep 2001, coll. S. Halse, J. Cocking and M. Scanlon, dissected on slide (WAM V 4205).

Paratypes

Spring water trickling through cobble/pebble substrate and flowing into Cangan Pool on Cockerega Creek, a tributary of Yule River, site PHC02 of WA Monitoring River Health Initiative, 21°41'50"S 118°37'43"E, 14 May 1995, coll. P. Papas, 1 dissected and 1 whole-mounted on slide (WAM V 4206 and V4207) and 5 Oct 1995, coll. M. Smith, 1 dissected on 2 slides (WAM V 4209). Bedrock/cobble/pebble substrate at Palm Springs, Fortescue River, 21°51'31"S 116°30'57"E, 6 Sep 2001, coll. S. Halse, J. Cocking and M. Scanlon, 1 dissected on slide (AP collection).

Conductivity at the collection sites ranged from 655 to 2580 μ S/cm and pH ranged from 7.72 to 8.06.

Etymology

Peniculus: latin diminutive of penis, referring to the rudimentary penial apparatus.

Description

Length of preserved incomplete specimens: holotype >11 mm, other specimens up to 10 mm. Width of X 0.48 – 0.52 mm. Prostomium bluntly rounded. Pharynx in II and III, oesophagus in IV –

IX, widening to intestine in X. Pharyngeal glands on pharynx and septa 2/3 – 6/7. Ventral chaetae paired from II, 80 – 120 µm long, largest in first few segments, one chaeta of each pair bifid with small upper teeth and a distal nodulus, the other narrower, without a nodulus and simple pointed (Figure 1A). Ventral chaetae absent on XII, present but not modified on XIII. Dorsal chaetae 1 or 2 (rarely 3) thin hairs per bundle from III, 150 – 325 µm long, paired support chaetae present.

Genitalia paired. Testes and ovaries in XI and XII respectively. Clitellum from ½XII to 13/14. Male funnels cup-shaped to tubular, narrow ciliated vasa deferentia penetrating the atrial muscle layer medially (Figure 2A) before travelling within the muscle layer and joining the atrial lumen at the start of the pseudopenis. Atria short and broad (360 × 75 – 450 × 112 µm), not folded, with thin muscle layer. Atria with tall glandular lining cells and a lumen that is narrow and apparently unciliated for most of its length but which becomes broader and ciliated just before joining the vasa deferentia at start of small protrusible pseudopenes. Pseudopenes small (35 – 45 µm long), each lying within a muscular sac and consisting of tall non-glandular lining cells with cilia projecting into the lumen (Figure 1C), terminating in a small papilla (essentially a rudimentary pendant penis) at the apex of a long (175 – 220 µm) invagination of the body wall. Vento-lateral male pores half way between 11/12 and 12/13. Small spermathecal vestibules with dorso-lateral pores at 12/13, leading to ampullae which extends over 1 or more segments, starting from XIV or more posteriorly (XIX – XXI in the holotype). Ampullae with loose sperm. Female funnels leading to ventro-lateral pores at 12/13.

Remarks

The two genera with dorso-lateral spermathecal pores (subfamily Phreodrilinae of Brinkhurst [1991]) are normally distinguished from one another by the presence of either pendant penes (*Antarctodrilus*) or pseudopenes (*Phreodrilus*). Presence of pendant penes would seem to be the plesiomorphic state and are thus assumed to have been lost (or at least reduced) in *Phreodrilus* species (Brinkhurst, 1991). In the new species, the papilla on which the male duct terminates is essentially a small pendant penis but the presence of a pseudopenis indicates that this species should be considered a member of the genus *Phreodrilus*. *Phreodrilus beddardi* Benham has a well developed convoluted pseudopenis which terminates in a similar papilla, albeit at the apex of a much shorter ectal invagination than that of the new species. The pseudopenes of *P. peniculus* are rudimentary compared to its congeners and appear only sufficiently well developed to provide enough flexibility for the ectal invagination to evert and

thus protrude the papilla from the male pores (as on specimen WAM V 4207).

Ciliation within the atrium has not been recorded for other phreodrilids so the finding of cilia in a short portion of the atrial lumen (but entad of the vas/pseudopenial union), as well as in the pseudopenis, prompted re-examination of other species, particularly of the genus *Phreodrilus*. Beddard (1891) described the highly coiled pseudopenis of *Phreodrilus subterraneus* Beddard as unciliated but Benham (1904) noted the presence of cilia within the same, but less coiled, structure of *Phreodrilus beddardi*. Neither author reported cilia within the atrium (termed a diverticulum by them). Other species descriptions have not noted the presence of cilia in these organs, but examination of specimens of *Phreodrilus branchiatus* Beddard in the author's collection and the type material of *Phreodrilus diemenensis* Pinder and Brinkhurst revealed cilia in the coiled pseudopenis of these species, with ciliation also extending much further into the non-pseudopenial part of the atrium than in *P. peniculus*. Cilia are also present in the coiled pseudopenis and in the ental part of the ejaculatory duct of a new *Phreodrilus* from Oman (B. Sambugar pers. comm.). Ciliation could not be detected in the uncoiled pseudopenis and atrium of the single known specimens of *Phreodrilus melaleucensis* and *Phreodrilus mitodes*. The type (and only) specimens of the remaining member of this genus, *Phreodrilus mauienensis*, were not examined since they are known to be mounted in a medium that has obscured most of the internal anatomy. Species of other genera, including *Insulodrilus lacustris*, *Insulodrilus bifidus*, *Antarctodrilus micros*, *Antarctodrilus proboscidea*, *Antarctodrilus horwitzii* (all specimens in the author's collection) and the new *Astacopsidrilus* described below, were examined but these lacked ciliation in the atrium and ejaculatory duct.

Phreodrilus pseudopenes are thought (e.g. Brinkhurst 1965) to have arisen by separation of the muscle and lining tissues of the ectal part of the atrium, with subsequent elongation and coiling of the tube of lining tissue in some species. This seems to provide the inner tube with flexibility to match its muscular sac, allowing the whole structure to be protruded from the male pores (Beddard 1891; Brinkhurst 1965). Thus, an organ that is entirely glandular in most phreodrilid genera, has become partly modified as a sperm transport and copulatory organ in *Phreodrilus*. Ciliation of the pseudopenis may be an apomorphic trait associated with this modification, aiding the passage of sperm through the narrow duct, as in the vas deferens. Absence of ciliation in some *Phreodrilus* might indicate more than one lineage within the group, although *P. subterraneus* should be re-examined as it is undoubtedly closely related to congeners with

highly coiled pseudopenes and it would be surprising if cilia were absent in the pseudopenes of this species.

Astacopsidrilus edwardi sp. nov.

Figures 1B and 2B

Material examined

Holotype

Temporary seepage on Merredin Rock, Merredin, 31°28'S 118°17'E, 5 Jul 1996, coll. D. Edward, 1 dissected on slide (WAM V 4210).

Paratypes

Type locality and date, 4 mature on slides, 3 mature and 6 immature in alcohol (WAM V 4211 – WAM V 4215) and 1 mature on slide (AP collection). Seepage on Boorabbin Rock, 95 km east of Southern Cross, 120°16'S 31°12'E, 5 Jul 1996, 1 mature and 6 immature on slides, 1 mature and 10 immature in alcohol (WAM V 4221 – WAM V 4228). Seepage on Woorkabing Hill, about 20 km north of Wickiepin, 32°38'00"S 117°26'E, 11 Jun 1995, 3 mature and 1 immature on slides, 2 mature in alcohol (WAM V 4229 – WAM V 4233). All collected by D. Edward.

Etymology

Named in honour of the collector, Dr. Donald H.D. Edward (Zoology Department, The University of Western Australia).

Description

Length of preserved specimens 10 – 15 mm. Width of X 0.4 – 0.5 mm. Number of segments 46 to 69. Prostomium bluntly rounded. Pharynx in II – III, pharyngeal glands on pharynx and septa 3/4 – 6/7. Gut enlarging in X, most specimens with a thick layer of chlorogogue cells on gut and most septa. Ventral chaetae paired from II, mostly 95 – 125 µm long, longest in first few segments, both chaetae with rudimentary upper teeth and a distal nodulus (Figure 1B). Ventral chaetae of XIII (and often of XI and/or XIV) paired within enlarged glandular sacs, one of each pair long (107 – 192 µm) with hollow distal half and sharp tip, projecting from the sac, and one shorter and mostly contained within the sac. Dorsal chaetae 1 or 2 short (75 – 132 µm) thin hairs per bundle, each with a pair of support chaetae. Hairs hardly visible at low magnification.

Genitalia paired. Testes and ovaries in XI and XII respectively. Clitellum from ½XII to 12/13. Male funnels cup-shaped on 11/12, feeding ciliated vasa

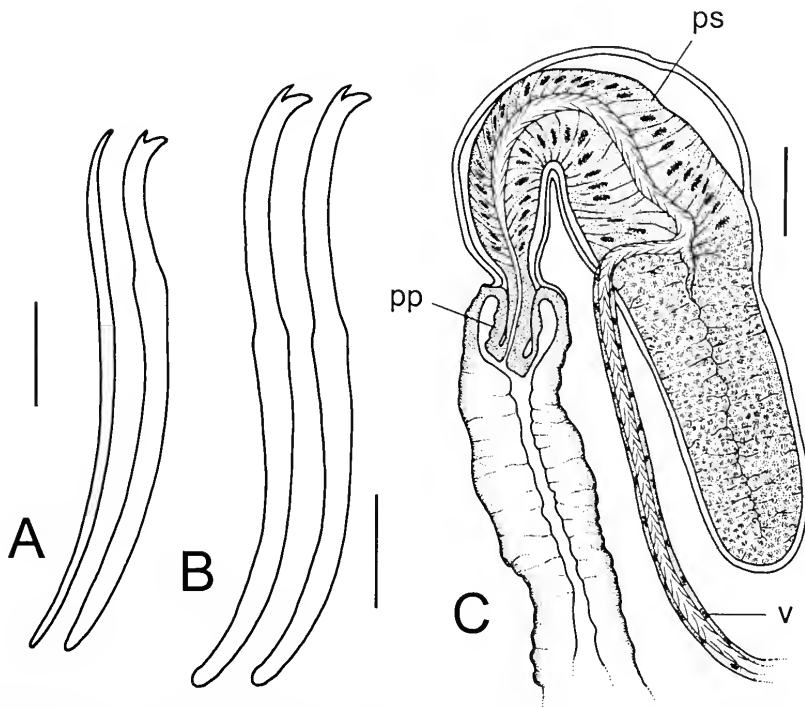


Figure 1 A, pair of ventral chaetae of *Phreodrilus peniculus* sp. nov.; B, pair of ventral chaetae of *Astacopsidrilus edwardi* sp. nov.; C, male genitalia of *Phreodrilus peniculus* sp. nov. paratype V4206. Scale lines: A and B, 20 µm; C, 50 µm. pp, pendant penis; ps, pseudopenis; v, vas deferens.

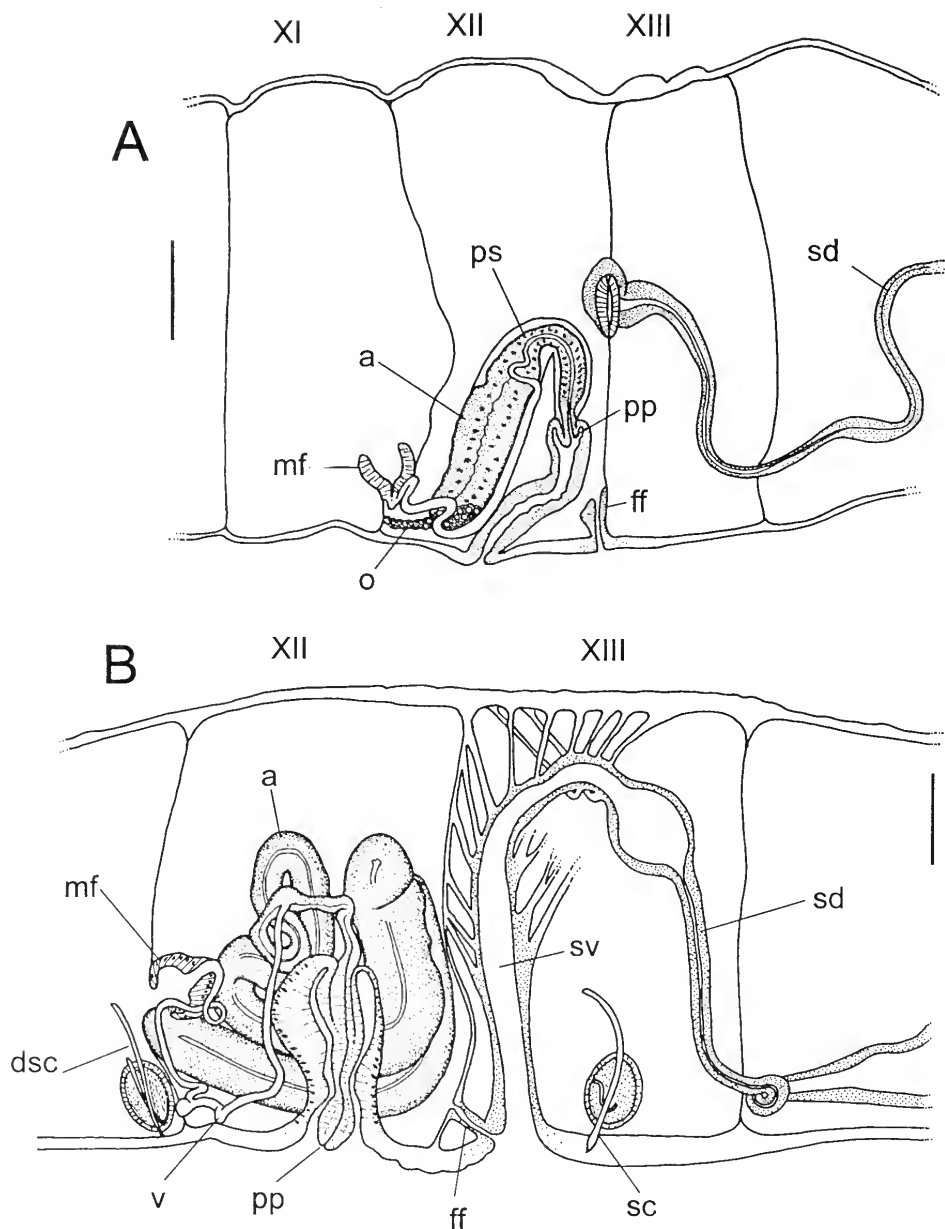


Figure 2 A, genitalia of *Phreodrilus peniculus* sp. nov. holotype; B, genitalia of *Astacopidrilus edwardi* sp. nov. holotype. Scale lines: A and B, 100 μ m. a, atrium; dsc, duplicate spermathecal chaeta; ff, female funnel; mf, male funnel; o, ovary; pp, pendant penis; ps, pseudopenis; sc, spermathecal chaeta; sd, spermathecal duct; sv, spermathecal vestibule; v, vas deferens.

deferentia. Convolted atria long and moderately broad (875 x 125 – 1300 x 112 μ m) with narrow lumen, narrowing to form ejaculatory ducts (width 15 – 20 μ m) after union with the vasa deferentia (Figure 2B). Pendant penes well developed, within penis sacs which open ventro-laterally mid-way

between 11/12 and 12/13. Spermathecal vestibules tall and muscular with ventro-lateral openings on anterior of XIII (Figure 2B). Vestibules with muscular attachments to dorso-lateral and dorsal body wall and septa 12/13, giving rise to spermathecal ducts each with a swelling ectally

(Figure 2B). Spermathecal vestibules and ducts (and possibly the ampullae) replicated in XIV in one specimen. Spermathecal ampullae, with loose sperm in mated individuals, extending from XIV to as far posterior as XVIII. Female funnels ventrolateral on 12/13 leading to pores within spermathecal vestibules (Figure 2B).

Remarks.

The tall muscular spermathecal vestibules incorporating the female pores are characteristic of species of the genus *Astacopsidrilus*. Of its congeners, the new species is most similar to *Astacopsidrilus ostiensis* Pinder and Erséus, 2000, an estuarine species from Tasmania and *Astacopsidrilus beckettiae* Pinder and Brinkhurst, 1997, from streams on subantarctic Campbell Island. It is distinguished from both of these by the swelling on the spermathecal ducts. In addition, *A. beckettiae* has narrower atria (<30 µm), lacks the narrow ejaculatory ducts and has smaller chaetae, while *A. ostiensis* has much larger penes and broader spermathecal vestibules.

Insulodrilus bifidus Pinder and Brinkhurst

Insulodrilus bifidus Pinder and Brinkhurst, 1997, 491, Figures 109–112.

Material examined

This species has been identified from numerous additional localities in the vicinity of those listed by Pinder and Brinkhurst (1997) (Walpole to Lake Muir region) but also the following sites which represent range extensions. Various streams near Pemberton (such as Carey Brook and Treen Brook) sampled by the author and K. Trayler, confirming the tentative identification from this region in Pinder and Brinkhurst (1997); Lake Jasper, 34°25'16"S 115°41'29"E, 14 Sep 1996, coll. A. Pinder and R.O. Brinkhurst; Helena River, 31°56'37"S 116°26'11"E, 29 Oct 1997; Lake Pleasant View, 34°49'51"S 118°10'59"E 29 Sep 1998; Qualeup Lake, 33°50'19"S 116°45'52"E, 9 Oct 1998; Nalyerin Lake, 33°08'51"S 116°22'15"E, 8 Oct 1998; Ngopitchup Swamp, 33°57'27"S 117°20'32"E, 27 Aug 1998. Specimens from the latter sites all collected by A.M. Pinder and J.M. McRae and retained by the author.

Remarks

This species is readily identified by its single bifid chaeta per dorsal bundle, instead of the usual hair chaetae. It is the most common phreodrilid in the higher rainfall south-west, extending north to at least the Helena River and is the only phreodrilid known from wetlands in the south-west (other than habitats on granite outcrops) in areas with rainfall less than 800 mm.

Antarctodrilus micros Pinder and Brinkhurst

Antarctodrilus micros Pinder and Brinkhurst, 1997, 467, Figures 45–47.

Material examined

Lake Smith, 34°25'52"S 115°07'52"E, 14 Sep 1996, 3 mature on slide, several in alcohol, coll. A. Pinder and R.O. Brinkhurst (AP collection). Twilight Cave, 31°33'53"S 115°41'25"E, 27 Aug 1994, Yanchep National Park, 3 mature on slides, coll. E.J. Jasinska (AP collection). Carpark Cave, 31°33'11"S 115°40'54"E, 31 Nov 1996, Yanchep National Park, 1 on slide, coll. E.J. Jasinska (AP collection). Kudjal Yolgah Cave, 34°05'55"S 115°02'45"E, 10 Apr 1993, Leeuwin-Naturalist Caves, 3 mature on slide, coll. E.J. Jasinska (AP collection).

Remarks

The new specimens conform to the original description, except for the slightly larger atria (up to 200 x 56 µm) than those described for the holotype (160 x 47 µm). However, there is some variation in the length of this organ in most phreodrilids. As for the type specimens, the genital organs are shifted forwards by several segments compared to their normal position for the family (segments XII and XIII). On one specimen male and spermathecal pores are on V and VI respectively. An examination of the new and type material suggests that the muscle and lining tissue are separate between the vas deferens/atrial union and the penis, but, considering the very small size of this area, I am reluctant to conclude that this is homologous with the pseudopenes of *Phreodrilis* at this stage. All *Phreodrilus* described so far have the ventral chaetae of a pair dissimilar (i.e. one bifid and one simple-pointed) whereas *A. micros* has both chaetae of a pair bifid, as in many other members of the probably paraphyletic *Antarctodrilus*.

Antarctodrilus micros is known from surface and cave waters of the Warren bioregion and from streams in a number of caves just north of Perth. The latter represent a significant range extension for this species.

Antarctodrilus horwitszi Pinder and Brinkhurst

Antarctodrilus horwitszi Pinder and Brinkhurst, 1997, 469, Figures 48–51.

Material examined

Tributary of Deep River on eastern portion of Meredith Road, 34°58'54"S 116°37'47"E, 8 Sep 1996, 1 on slide; Carey Brook at Pile Road crossing, 34°21'29"S 115°54'29"E, 16 Sep 1996, 2 on slides; Collier Creek on road running east of Cemetery Road, 34°58'30"S 116°46'00"E, 11 Sep 1996, 2 on slides; Upper tributary of Beedelup Brook South,

34°22'18"S 115°56'15"E, 16 Sep 1996, 1 on slide. All collected by A. Pinder and R.O. Brinkhurst.

Remarks

The original description of *A. horwiti* was based on the single type specimen, each atrium of which has a broad sperm-filled lumen for its entire length. By contrast, the new specimens have thick atrial lining tissue with a narrow lumen, although the ental extremity of the atrium has a broad sperm filled lumen and thinner lining tissue in some specimens. These differences in atrial histology may represent different stages in the reproductive cycle. The new specimens otherwise closely resemble the holotype. Their atria are of a similar shape but slightly smaller size ($378 \pm 55 \mu\text{m} \times 55 \pm 5 \mu\text{m}$, $n=4$, compared to $500 \times 75 \mu\text{m}$ in the holotype). Considering that the new specimens are incomplete, their original length ($>6 \text{ mm}$) is probably not dissimilar to the holotype (9.8 mm) and the number and form of the chaetae also agree with the holotype. The new specimens have pre-clitellar ventral chaetae 113 to 122 μm long, compared to 112 to 138 μm on the holotype. The ventral chaetae of the holotype were wrongly measured as 77 to 108 μm in Pinder and Brinkhurst (1997). There is still no indication of where the vasa deferentia join the atria.

This species has been collected only in the Warren bioregion of south-western Australia. The new records confirm that this species occurs at least as far west as the Pemberton area, as supposed from immature specimens by Pinder and Brinkhurst (1997).

Phreodrilid WA3

Phreodrilid WA3 is one of the undescribed species listed by Pinder and Brinkhurst (1997). This distinctive worm (with up to 50 short hairs per dorsal bundle posteriorly, Figure 166 op. cit.) is common in the Warren region but has now also been recorded from Lesmurdie Falls near Perth. Unfortunately, specimens that are both mature and complete (i.e. with the distinctive tail end) have not yet been collected.

DISCUSSION

Although the far south-west of Western Australia still appears to be an area of particularly high phreodrilid diversity, comparable only to Tasmania in the number of species and level of endemism (Pinder 2001), the new species show that the family is certainly not restricted to this region and suggest there may be considerable diversity in suitable microhabitats further inland and north.

Phreodrilus peniculus is the first phreodrilid to be described from northern Australia and is one of the

undescribed species noted from north-western Australia by Pinder (2001). Thus far, all northern Australian surface waters from which phreodrilids have been found have been reaches of seasonal rivers which have cobble/gravel sediments and/or receive water from perennial springs. This suggests a hyporheic/groundwater association, although oligochaetes have not been well surveyed in other habitats in the region. Immature phreodrilids have been collected from groundwater in the north-west and interior of Western Australia by Dr William Humphries (Western Australian Museum) and Dr Brenton Knott (The University of Western Australia). Other groundwater phreodrilids have been described from North Africa (Giani *et al.*, 1995) and New Zealand (Benham, 1904), and phreodrilids have been recovered from groundwater in the Middle-East (B. Sambugar, pers. comm.).

Granite outcrops are another habitat where phreodrilids are turning out to be especially diverse. *Astacopsidrilus edwardi* is one of five new phreodrilid species recorded on granite outcrops in southern Western Australia (Pinder, 2001; Pinder *et al.*, 2000), most of which were collected by Dr. Donald Edward. Unfortunately, there is insufficient material to describe the other species. So far, the five species are known from just 10 outcrops, with each outcrop having only 1 species. All specimens of *A. edwardi* were collected from seepages arising from herbaceous meadows on granite outcrops. These seepages are temporary habitats, occurring for periods of days to months depending on the season and amount of recent rainfall and both the seepages and herbaceous meadows are completely dry for many months each year. This seems an extreme habitat for aquatic oligochaetes, particularly for phreodrilids which normally occur in habitats with at least some perennial moisture. The three localities listed for *A. edwardi* are all in inland areas with average annual rainfall between 275 and 450 mm and one of the undescribed outcrop species occurs in an area with rainfall less than 200 mm. By contrast, the several phreodrilid species occupying other types of surface waters in the south-west appear to be restricted to the more coastal areas with rainfall 500 to 1400 mm, with all but one of these (*Insulodrilus bifidus* Pinder and Brinkhurst, 1997) known only from areas with rainfall greater than 800 mm (Pinder, 2001). Evidence for the lack of phreodrilids in other types of wetlands in lower rainfall areas of the south-west comes from an extensive (but as yet unpublished) survey of invertebrates from a wide variety of wetland types in the wheatbelt (most of which are seasonally dry), being carried out by the Department of Conservation and Land Management. Thus, granite outcrops appear to be islands of phreodrilid diversity in the drier inland south-west. The reasons for this are not clear. One

consideration is that granite outcrops are largely impervious substrates and thus retain fresh surface moisture more readily than other aquatic habitats following rainfall events. Bayly (1997) and Pinder *et al.* (2000) discuss the diversity and uniqueness of invertebrate assemblages occupying aquatic habitats on these outcrops. Most of these other invertebrates occupy pools rather than seepages, with the significant exception of the chironomid genus *Archaeochlus*, which, like the phreodrilids, appears to have a global distribution indicative of a Gondwanan origin (Cranston *et al.*, 1987; Edward, 1989). Both these and the phreodrilids may have preferentially survived on granite outcrops as the south-west became increasingly arid from the mid-Tertiary. The ability of the granite outcrop worms to survive dry periods has not been investigated but presumably involves desiccation resistant cocoons.

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A new genus of Candoninae (Crustacea, Ostracoda, Candonidae) from the subterranean waters of southwestern Western Australia

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Abstract – A new ostracod genus, *Acondona* gen. nov., is described from subterranean waters of south-western Western Australia. Unlike other Australian Candoninae, it shows great similarities with some Holarctic genera, especially with the genus *Pseudocandona* Kaufmann, 1900. The two species known are described: *Acondona admiratio* sp. nov. and *A. memoria* sp. nov. The first species is characterized by the presence of “Tf” and “Tg” setae on the penultimate segment of the cleaning leg. The latter species lacks the “Tf” seta, but has a variable number of setae (two or three) on the basal segment of the same leg. Both new species have a characteristic hemipenis, which clearly separates them from other known Candoninae species.

INTRODUCTION

Recent investigations in Western Australia have led to an unprecedented discovery of a biodiverse subterranean biota, comprising numerous short range endemic taxa. Amongst these findings is a rich groundwater fauna (stygo fauna), many taxa of which have been described in the last decade (Poore and Humphreys, 1992; 1988; Wilson and Ponder, 1992; Bartsch, 1993; Humphreys, 1993a; 1993b; 1993c; 2001; Bruce & Humphreys, 1993; Harvey *et al.*, 1993; Baltanas and Danielopol, 1995; Pesce *et al.*, 1996a; 1996b; Pesce and De Laurentis, 1996; Yager and Humphreys, 1996; Bradbury and Williams, 1996a; 1996b; 1997a; 1997b; Harvey, 1998; De Laurentis *et al.*, 1999; 2001; Knott and Halse, 1999; Watts and Humphreys, 1999; 2000; 2002; in press; Wouters, 1999; Bradbury, 2000; 2002; Danielopol *et al.*, 2000; Jaume and Humphreys, 2001; Jaume *et al.*, 2001; Karanovic *et al.*, 2001; Karanovic and Pesce, 2002; Lee and Huys, 2002).

Ostracods, almost exclusively of the subfamily Candoninae Kaufmann, 1900, are a very important component of any subterranean fauna. Karanovic and Marmonier (2002, in press) described three new genera and 14 new species of Candoninae from subterranean waters of Western Australia making a total of 22 living genera in the subfamily (Karanovic and Marmonier, in press). The following genera are restricted to subtropical and tropical regions: *Terrestricandona* Danielopol and Betch, 1980; *Caribecandona* Broodbakker, 1983; *Cubacandona* Broodbakker, 1983; *Danielocandona* Broodbakker, 1983; *Indocandona* Gupta, 1984; *Namibicypris* Martens, 1992 and *Meischcandona* Karanovic, 2001. Other than the recently described genera

(Karanovic and Marmonier, in press) plus *Terrestricandona*, *Caribecandona* and *Danielocandona*, the other genera restricted to the tropics and subtropics are monospecific, probably as a result of the paucity of research in groundwater to which Candoninae are largely restricted in tropical and subtropical areas. Further research on the biodiversity of subterranean life of those regions will probably lead to the discovery of more new Candoninae species and new genera. The remaining 12 genera of Candoninae are distributed mainly in the Holarctic, although some do have a wider distribution. Among these 12 genera only *Phreatocandona* Danielopol, 1978 and *Paracandona* Hartwig, 1899 have but one living species, the remaining genera being more speciose. In order of species richness these are *Pseudocandona* Kaufmann, 1900 (about 75 species); *Candona* Baird, 1845 (ca. 45 recent species); *Baicalocandona* Mazepova, 1976 (ca. 30 species); *Candonopsis* Vavra, 1891 (25 living species); *Trapezicandona* Shornikov, 1969 (21 species); *Cryptocandona* Kaufmann, 1900 and *Eucandona* Daday, 1900 (ca. 12 species each); *Schellencandona* Meisch, 1996 (five recent species); *Nannocandona* Ekman, 1914 and *Trajancandona* Karanovic, 1999a (two species each) (Meisch, 1996; Karanovic, 1999; Karanovic and Marmonier, 2002).

The taxonomy of the subfamily is based on the morphological features of the carapace and soft parts. The main characteristic that unites all 22 genera within the same subfamily is the absence of the swimming setae on the antenna. The appearance of the male's copulatory organ is important for generic discrimination. Because some species reproduce exclusively

parthenogenetically, this organ is unknown and so the generic position of such species is still uncertain. In addition, most species, mainly in the genus *Candona*, were described decades ago and insufficiently for current generic determination because many new characters have been introduced into generic diagnoses. The first serious attempt towards the revision of the subfamily was made by Meisch (1996), who tried to distinguish several European genera according to the appearance of cleaning leg. However, considerably more work needs to be done to understand the zoogeography and evolution of the subfamily Candoninae.

In this paper another new genus of Candoninae, containing two new species, is described from the subterranean waters of Western Australia.

MATERIAL AND METHODS

Samples were collected with haul-nets (mesh sizes from 250 or 350 micrometers) from subterranean water monitoring bores (Yilgarn site) and with hand-nets from caves (Margaret River sites).

Haul-nets are simple plankton nets of a size suitable for the bore, which can range from 30 to 180 mm in diameter. Weighed nets were lowered down into the bore with one bottle screwed on its distal part and hauled through the water column, usually a number of times. From caves samples were taken by sweeping with hand nets (15–20 cm diameter) through pools, including submerged tree roots.

All samples were sorted while alive under dissecting microscope and the ostracods were then fixed in 75% ethanol and assigned a field number (Prefix BES for Yilgarn site; CW for Margaret River sites).

Ostracods were dissected in a mixture of distilled water and glycerol (1:1) with fine entomological needles (mark 000). Dissected appendages and valves of some specimens were mounted in Faure's medium, which was prepared following the procedure discussed by Stock & Vaupel Klein (1996). All non-dissected material is preserved in 75% ethanol in glass test-tubes. Drawings have been prepared using a drawing tube attachment on Leica-DMLS brightfield compound microscope, with C-PLAN achromatic objectives.

In the systematic part of this paper the length (L) of all segments was measured in the middle of the segments, and length ratios are presented beginning with the proximal end. All appendages are named according to Martens (1998). The chaetotaxy of all limbs follows the model proposed by Broodbakker & Danielopol (1982), revised for the antenna by Martens (1987), and for the third thoracic leg by Meisch (1996). Lobes

on hemipenis are labelled according to Danielopol (1969).

Abbreviations used in the text and figure legends: a1 and a2 – lateral (or outer) lobes on hemipenis; A1 – antennula; A2 – antenna; b – medial lobe on hemipenis; BES and CW- prefixes for the field numbers; e – *bursa copulatrix*; d1, d2, dp – setae on basal segment T3; Fu – furca; g – “M” process (middle chitinous part) of hemipenis; G1, G2, G3, GM, Gm – antennal claws; H – height; h – inner lobe on hemipenis; L – length; LV – left valve; Md – mandible; Mxl – Maxillula; RV – right valve; Ta, Tb, Td – setae on T1; Te, Tf, Tg, Th1, Th2, Th3 – setae on endopodal segments T3; T1, T2, T3 – first, second and third thoracopods; t1, t2, t3, t4 – setae on the second endopodal segment A2; W – width; WAM – Western Australian Museum; Y, ya, y1, y2, y3 – aesthetascs; z1, z2, z3 – apical setae on the second endopodal segment A2.

SYSTEMATICS

Family Candonidae Kaufmann, 1900

Subfamily Candoninae Kaufmann, 1900

Genus *Acandona* gen. nov.

Diagnosis

Carapace subtriangular to triangular. LV overlaps RV dorsally with flange. Valves asymmetrical. Valve surface smooth. A1 seven-segmented. Male's A2 with developed sexual bristles. Exopodite of same appendage with two short and one long seta. Md palp with 3+2 setae in bunch on second segment, same segment externally with two setae; penultimate segment with three setae externally, and four setae distally to intero-distally; gamma seta being smooth. Terminal segment with central claw fused with segment, which squarish. Mxl palp with rectangular terminal segment and same segment with six appendages (two claw-like; four seta-like). Male's prehensile palps strongly asymmetrical, right one being robust; both palps with two subterminal sclerotized structures well developed. Exopodite of T1 with two setae. Same appendage with one “Ta” seta present on protopodite as well as “Tb” and “Td” setae. T2 five segmented; basal segment with seta. T3 limb five segmented; basal segment with all three setae, or seta “d2” missing. Penultimate segment clearly divided, and with “Tf” seta present or absent; terminal segment with setae “Th2” and “Th3” long, while seta “Th1” short. Fu with all setae and claws developed. Hemipenis with lateral shield subdivided into two lobes, “a1” triangular and extended from rest of hemipenis's parts, while “a2” rounded. “M”-process very weakly sclerotized. Lobes “b” and

"h" present. Zenker's organ with seven rows of spines.

Type species

Acandona admiratio sp. nov.

Other species

Acandona memoria sp. nov.

Etymology

The generic name consists of the first alphabet letter "A" and the genus name *Candona*. Gender feminine.

Acandona admiratio sp. nov

Figures 1–6

Material Examined

Holotype

Male (WAM C28395) – Western Australia, Margaret River, Easter Cave, Tiffanys Lake, 12 March 2002, leg. S. Eberhard, 34°16'40"S, 115°06'09"E (CW 00 146); dissected on one slide.

Allotype

Female (WAM C28396) – Western Australia, Margaret River, Easter Cave, Tiffanys Lake, 12

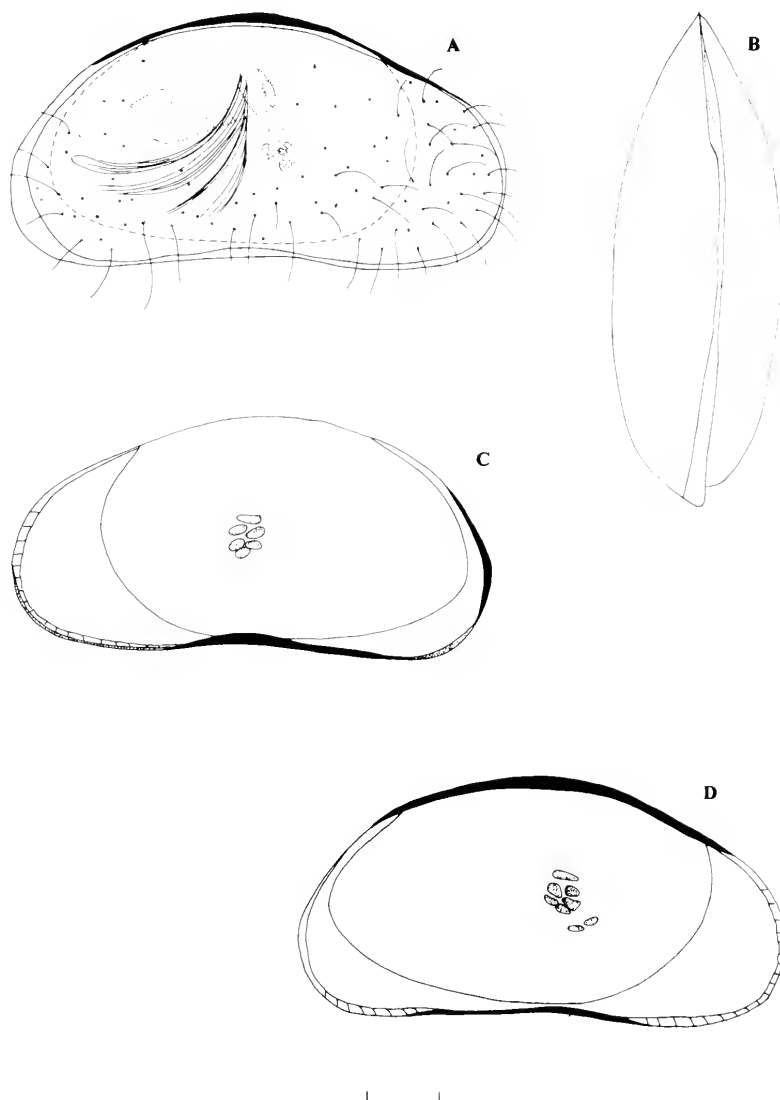


Figure 1 *Acandona admiratio* gen. nov., sp. nov. A, B holotype male (L 0.673 mm); C, D male WAM C28400 (L 0.67 mm): A – carapace, external view from right side; B – carapace, dorsal view; C – RV, internal view; D – LV, internal view. Scale = 0.1 mm.

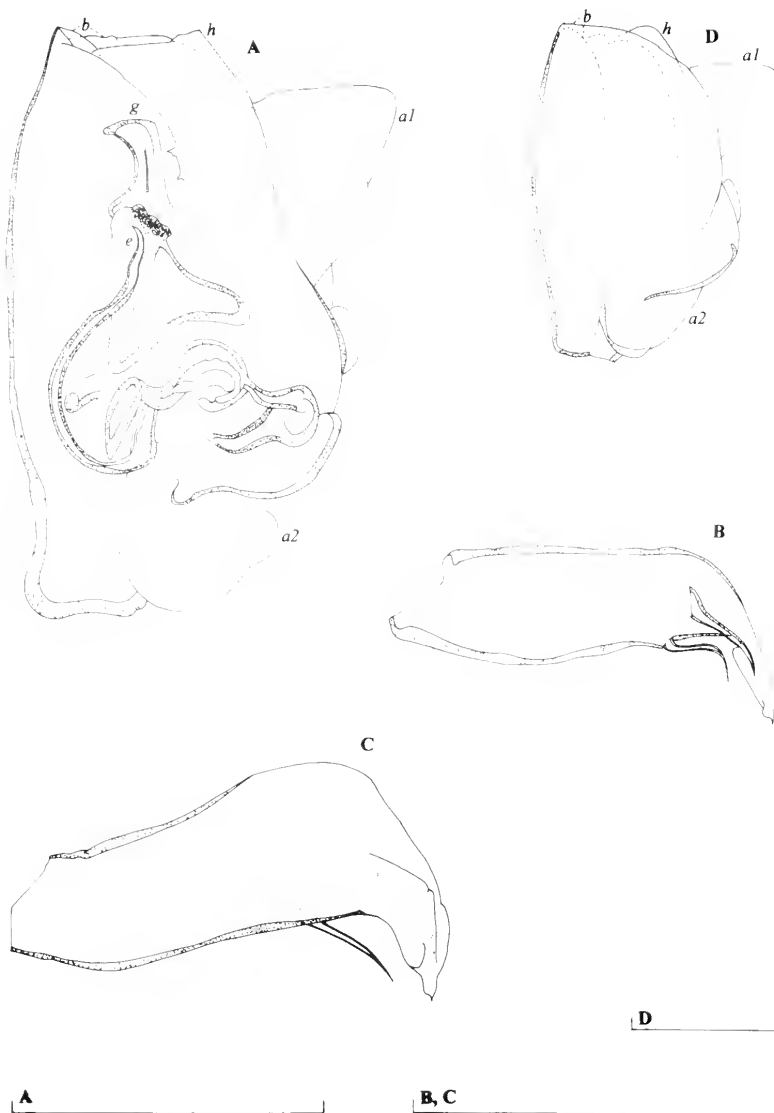


Figure 2 *Acondona admiratio* gen. nov., sp. nov. A–C holotype male (L 0.673 mm); D male WAM C28400 (L 0.67 mm): A – hemipenis, lateral view; B – left prehensile palp; C – right prehensile palp; D – hemipenis, medial view. Scales = 0.1 mm.

March 2002, leg. S. Eberhard, 34°16'40"S, 115°06'09"E (CW 00 146): dissected on one slide

Paratypes

Western Australia, Margaret River, Easter Cave, Tiffanys Lake, 12 March 2002, leg. S. Eberhard, 34°16'40"S, 115°06'09"E (CW 00 146): six females [one on slide (WAM C28397), others in alcohol (WAM C28398)].

Other material

Western Australia, Margaret River, Easter Cave, Mouse Hole 1, 05 February 2002, leg. S. Eberhard, 34°16'36"S, 115°06'04"S (CW 00 008): one juvenile in alcohol (WAM C28399).

Western Australia, Margaret River, Easter Cave, Mouse Hole 2, 05 February 2002, leg. S. Eberhard, 34°16'36"S, 115°06'04"S (CW 00 009): one male, two females, and three juveniles [male on slide (WAM



Figure 3 *Acondona admiratio* gen. nov., sp. nov., holotype male (L 0.673 mm): A – Md, B – A2, C – A1; D – terminal segment of A1, with aesthetasc; E – Mxl palp; F – claws on the third endite of Mxl. Scale = 0.1 mm.

C28400), other specimens in alcohol (WAM C28401)].

Western Australia, Margaret River, Jewel Cave, Flat Roof 2, 06 March 2002, leg. S. Eberhard, 34°16'22"S, 115°05'38"S (CW 00 118): 1 juvenile in alcohol (WAM C284002).

Western Australia, Margaret River, Easter Cave, Lake Roots, pool with roots, 16 April 2002, leg. S. Eberhard, 34°16'41"S, 115°06'10"S (CW 00 205): one male, three females and three juveniles, all in alcohol (WAM C284003).

Description

Male (holotype). L of LV 0.673 mm, H situated in middle and equalling 49.8% of L. RV being smaller and 0.65 mm long, with greatest H as well in middle and equalling 44.5% of L. Carapace in lateral view (Figure 1A) triangular. Doral margin arched, inclined towards frontal, while rounded towards caudal margin. Both caudal and frontal margins rounded, frontal being wider than caudal one. Ventral margin slightly concave around middle. LV overlaps right one with clear flange dorsally, while



Figure 4 *Acondona admiratio* gen. nov., sp. nov., holotype male (L 0.673 mm): A –T2; B –T3; C – Fu; D – furcal attachment; E – rake like organ. Scales = 0.1 mm.

RV overlaps left one, with pronounced selvage, on small patch postero-ventrally. Marginal zone wider anteriorly (20% of L) than posteriorly (10% of L). Marginal pore canals small and straight. Selvage peripheral. In dorsal view (Figure 1B) carapace frontally cuneiform and narrower than caudally. LV clearly overlaps right one on both ends. Greatest W around middle equaling 34% of L. Surface of carapace smooth and hairy.

A1 seven-segmented (Figure 3C). First segment with two setae anteriorly: proximal reaching distal margin of second segment (not shown on figure),

distal reaching only middle of same segment. Same segment with two setae posteriorly (almost reaching distal end of fifth segment). Second segment with one seta anteriorly which reaching distal end of fourth segment. Third segment without any seta. Fourth segment with two very long setae anteriorly, and one shorter posteriorly (reaching middle of penultimate segment). Fifth segment with two long setae anteriorly, and one shorter posteriorly (only slightly exceeding distal end of same segment). Penultimate segment with two long setae, and two shorter ones (reaching distal end of terminal

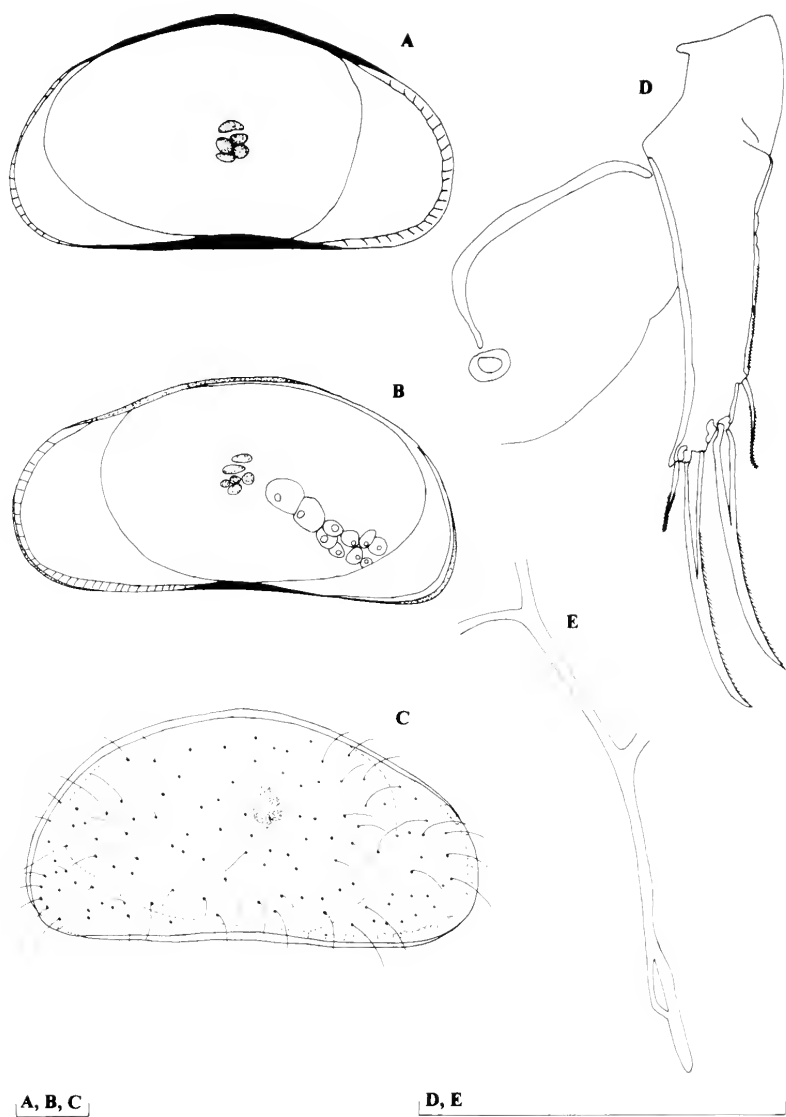


Figure 5 *Acandona admiratio* gen. nov., sp. nov. A, B, D, E allotype female (L 0.6 mm); C paratype female (L 0.62 mm): A – LV, internal view; B – RV, internal view; C – carapace, external view from right side; D – Fu with genital lobe, part of furcal attachment and vaginal aperture; E – furcal attachment. Scales = 0.1 mm.

segment) anteriorly, while same segment posteriorly carries one seta which exceeds distal end of terminal segment. Terminal segment with two long setae, one short (1.7 times longer than segment), and aesthetasc (ya) which 4.2 times longer than terminal segment. All five terminal segments of about same L.

A2 five-segmented (Figure 3B). Exopodite plate with one long seta and two shorter ones. Aesthetasc Y equals 54% of first endopodal segment; y1 slightly exceeds distal end of third segment; y2 about two

times as long as terminal segment; y3 six times as long as same segment. First endopodal segment postero-distally with two unequal setae: one reaching middle of terminal claws, other distal end of third segment. Male's bristles present. Penultimate segment with three long claws (G2 and two transformed setae – z1 and z2), subequally long (1.1 times as long as first endopodal segment). Penultimate segment with two smaller claws (G1 and G3) both being four times as long as terminal segment, and one short seta (z3) (2.5 times as long

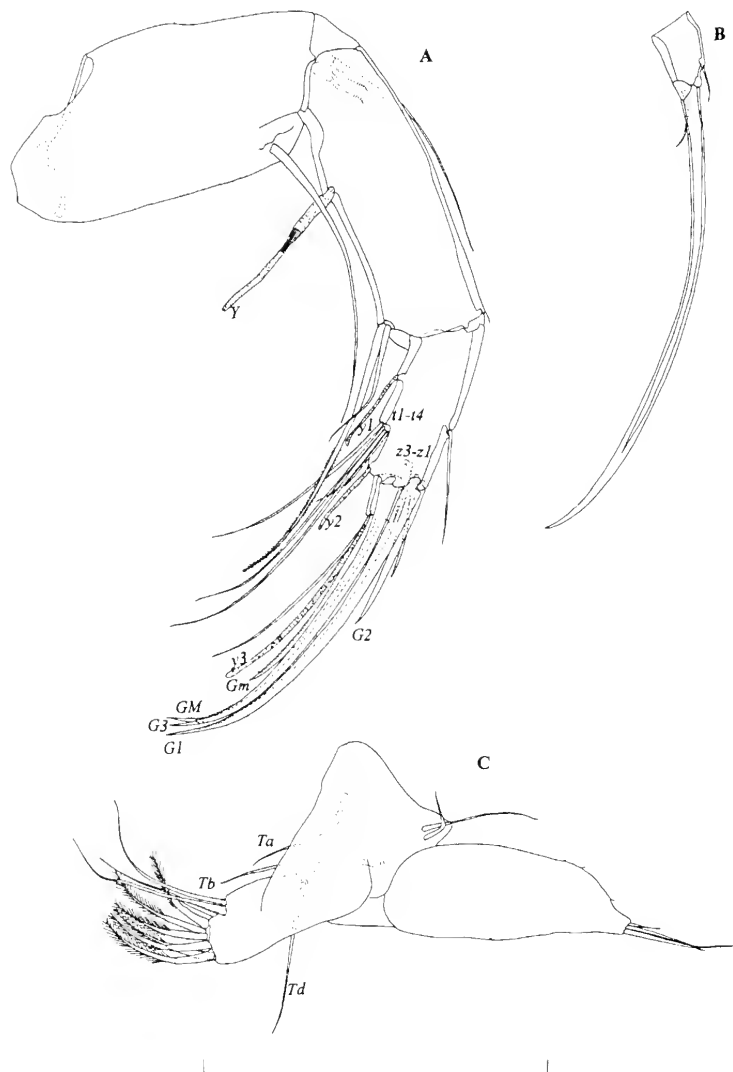


Figure 6 *Acandona admiratio* gen. nov., sp. nov., allotype female (L 0.6 mm): A – A2, B – terminal segment with claw of T2; C – T1. Scale = 0.1 mm.

as terminal segment). Terminal segment with long GM claw which 0.9 times as long as first endopodal segment, and small Gm claw two times as long as terminal segment. L ratios of four endopodal segments 8.5 : 3.2 : 2 : 1

Md (Figure 3A). Coxa with about eight terminal teeth. Palp 4-segmented. First segment with two long setae (pappose – S1), and two short (pappose – S2). Second segment with two setae externally (reaching middle of following segment), while internally with 3+2 setae in bunch. Penultimate segment with three setae externally, and four distally to intero-distally. Gamma seta smooth. Terminal segment with fused claw which distally

pappose. On external side of claw one strong, more claw-like seta, while on internal side two thin setae present. L : W of terminal segment 1 : 1. L ratios of three distal segments 1.7 : 2.4 : 1.

Mxl palp (Figure 3E) with penultimate segment which distally with four pappose setae. Terminal segment rectangular with two claws and four setae.

Prehensile palps on T1 asymmetrical: right one (Figure 2C) more robust than left one (Figure 2B). On both palps main body robust, fingers stocky. On both palps subterminal sclerotized structures elongated. Exopodite consists of two unequal setae. Protopodite with one "Ta" seta. Setae "Tb" and "Td" also present.

T2 (Figure 4A) 5-segmented. Basal segment with one seta. First and second endopodal segments with one seta each, penultimate segment with two setae. Terminal segment with two setae and claw which distally strongly serrated and 1.3 times as long as three distal segments combined.

T3 (Figure 4B) 5-segmented. Basal segment with only two setae (d1 and dp). First endopodal segment without any seta, penultimate segment clearly divided and with both "Tf" and "Tg" setae present. Terminal segment with three unequally long setae, "Th1" being 1.7 times as long as terminal segment. L ratios of three setae as follows 4.2 : 3 : 1.

Fu (Figure 4C) with both furcal claws and setae developed. Anterior claw slightly longer than posterior one, both claws serrated. Posterior furcal margin with short, stiff setae. L ratios of anterior furcal margin, anterior, and posterior claws 1.5 : 1.1 : 1. Posterior seta reaching distal end of posterior furcal margin. Furcal attachment shown on Figure 4D.

Hemipenis (Figure 2A) robust, with lobe "a1" triangular and extended, "a2" rounded, lobe "h" not evenly rounded, but more wavy, while lobe "b" widely rounded.

Zenker's organ with seven rows of spines.

Female (allotype). L of LV (Figure 5A) equals 0.6 mm, with greatest H around middle, equalling 56% of L. RV (Figure 5B) being equally long, and with greatest H 49% of L. Valves asymmetrical: left one clearly higher than right one, overlapping it with flange dorsally. RV overlaps left one postero-ventrally. Right valve with more straight caudal margin than in LV. Marginal zone frontally 23% of L, while caudally 13%. Greatest W (Figure 11B) equals 33% of L. Other features of carapace same as in male.

A2 4-segmented (Figure 6A). Aesthetasc Y equals 55% of first endopodal segment; y1 not reaching distal end of penultimate segment, y2 two times as long as terminal segment, while y3 5.3 times as long as same segment. All "t" setae on posterior side of second endopodal segment developed; while on anterior side of same segment one seta situated medially and slightly exceeding distal end of terminal segment. Seta z1 more claw like, while z2 and z3 seta like. Claw G2 3.8 times as long as terminal segment, G1 and G3 1.2 times as long as first endopodal segment. Claw GM as long as first endopodal segment, while Gm five times longer than terminal segment. All claws serrated. L ratio of three endopodal segments 7.3 : 4 : 1.

Endopodite of T1 (Figure 6C) with L ratio of three terminal setae 3.5 : 2.4 : 1.

T2 (Figure 6B) with smooth claw.

Fu (Figure 5D) with claws almost equally long, and 0.8 times as long as anterior furcal margin. Genital lobe rounded, and without any appendages.

All other morphological features same as in male.

Variability

Valve L of females range from 0.600 mm to 0.635 mm (average 0.619 mm; n=7), while in males they range from 0.670 mm to 0.673 mm (average 0.671 mm; n=3). No other forms of variability was observed.

Etymology

The species name comes from the Latin noun "admiratio" (f.), meaning wonder.

Acandona memoria sp. nov.

Figures 7–11

Material Examined

Holotype

Male (WAM C28404) – Western Australia, Yilgarn Craton, Upper Brockman, unused water bore on river terrace, 22 August 1999, leg. W. F. Humphreys, 31°21'S 116°07'E (BES: 7668): dissected on one slide.

Allotype

Female (WAM C28405) – Western Australia, Yilgarn Craton, Upper Brockman, unused water bore on river terrace, 22 August 1999, leg. W. F. Humphreys, 31°21'S 116°07'E (BES: 7668): dissected on one slide.

Paratypes

Western Australia, Yilgarn Craton, Upper Brockman, unused water bore on river terrace, 22 August 1999, leg. W. F. Humphreys, 31°21'S 116°07'E (BES: 7668): two females [one on slide (WAM C28406), other in alcohol (WAM C28407)].

Description

Male (holotype). L of LV 0.648 mm, greatest H situated around middle and equalling 54% of L. RV being smaller and 0.629 mm long, with greatest H as well around middle and equalling 50% of L. Carapace in lateral view (Figure 7A) subtriangular. Doral margin arched, slopping evenly towards frontal margin and more inclined towards caudal one. Caudal margin almost straight, while frontal one widely rounded. Ventral margin slightly concave around mouth region, than slightly convex frontally. LV overlaps right one with clear flange dorsally. Marginal zone wider anteriorly (17% of L) than posteriorly (7% of L). Marginal pore canals not observed. Selvage peripheral frontally, not visible caudally. Carapace in dorsal view (Figure 7B) frontally cuneiform and narrower than caudally. LV overlaps right one on both ends. Greatest W around middle equalling 33% of L. Surface of carapace smooth and hairy.

A1 7-segmented (Figure 9A). First segment with

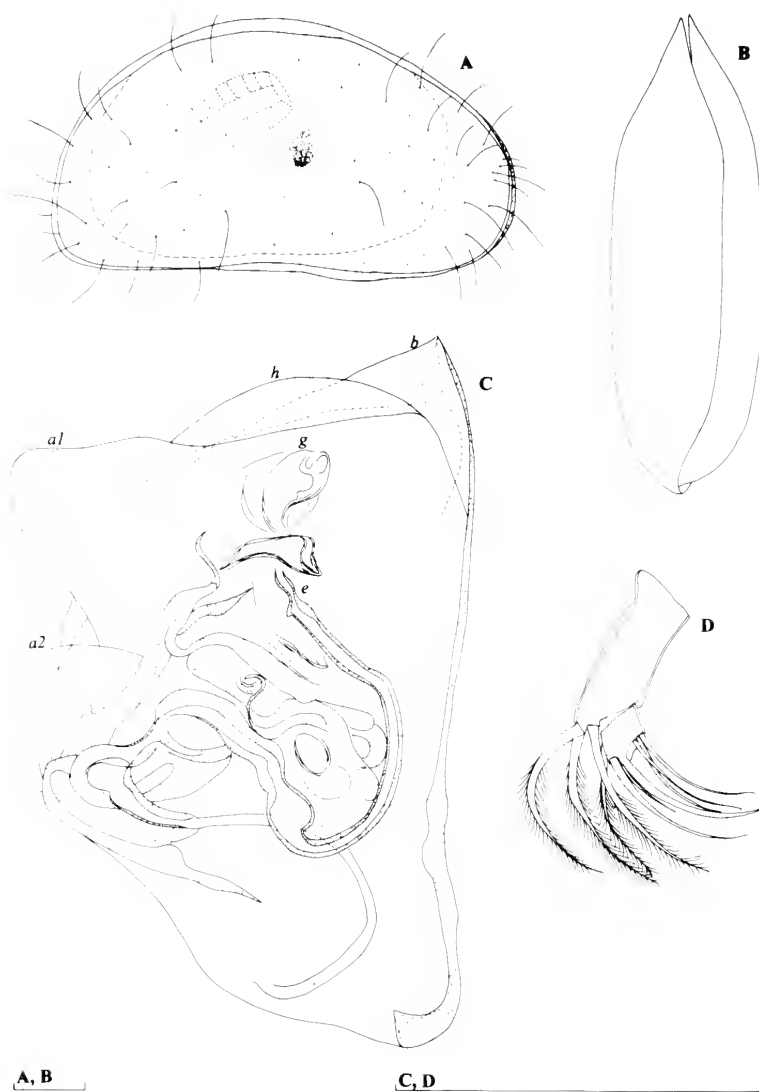


Figure 7 *Acandona memoria* gen. nov., sp. nov., holotype male (L 0.648 mm): A – carapace, lateral view from right side; B – carapace, dorsal view; C – hemipenis, lateral view; D – Mx1 palp. Scales = 0.1 mm.

two setae anteriorly (proximal reaching distal margin of second segment, distal reaching only middle of same segment), and two setae posteriorly (almost reaching distal end of fifth segment). Second segment with one seta anteriorly reaching distal end of fourth segment. Third segment without any seta. Fourth segment with two long setae anteriorly, and one shorter posteriorly (reaching middle of following segment). Fifth segment with two long setae anteriorly, and one shorter posteriorly (reaching middle of terminal segment). Penultimate segment with two long setae, and short one

(hardly reaching distal end of terminal segment) anteriorly, while same segment more posteriorly carries one seta that exceeds distal end of terminal segment. Seventh segment with two long and one short seta (about two times longer than segment), and aesthetasc (ya) 5.4 times longer than terminal segment. All five terminal segments of about same L.

A2 5-segmented (Figure 9C). Exopodite plate with one long seta and two short ones. Aesthetasc Y equals 62% of first endopodal segment; y1 slightly exceeds distal end of third segment; y2 about two times as long as terminal segment; y3 six times as



Figure 8 *Acondona memoria* gen. nov., sp. nov., holotype male (L 0.648 mm): A –T2; B –T3; C – left prehensile palp; D – right prehensile palp. Scale = 0.1 mm.

long as same segment. First endopodal segment postero-distally with two unequal setae: one reaching middle of terminal claws, other distal end of penultimate segment. Male's bristles present. Penultimate segment with three long claws, subequally long (1.4 times as long as first endopodal segment), that represent claw G2 and two transformed z setae (z1 and z2). Penultimate segment also with two smaller claws – G1 (4.5 times as long as terminal segment), and G3 (four times as long as terminal segment), as well as with one short – z3 seta (two times as long as terminal segment). Terminal segment with two claws: GM (1.1 times as

long as first endopodal segment), and Gm (three times longer than terminal segment). L ratios of four endopodal segments 7.7 : 2.4 : 2 : 1

Md (Figure 9D). Coxa with about seven terminal teeth. Palp four-segmented. First segment with two long setae (pappose – S1), and two short (pappose – S2). Second segment with two setae externally (reaching middle of following segment), internally with 3+2 setae in bunch. Penultimate segment with three setae externally, and four intero-distally. Gamma seta smooth. Terminal segment with fused claw, distally pappose. On external side of claw one strong seta, internally two thin setae present. L : W



Figure 10 *Acandona memoria* gen. nov., sp. nov. A, B holotype male (L 0.648 mm); C–F allotype female (L 0.619 mm): A – Fu; B – furcal attachment; C – Fu with genital lobe; D – furcal attachment; E – protopodite of T1; F – T2, detail. Scale = 0.1 mm.

as long as terminal segment. L ratios of three setae as follows 3.5 : 2.2 : 1.

Fu (Figure 10A) with both furcal claws and setae developed. Anterior and posterior claws almost equally long and finely serrated. Posterior seta situated very low on furcal trunk. Claws 0.9 times as long as anterior furcal margin. Furcal attachment shown on Figure 4B.

Hemipenis (Figure 7C) robust, with lobe "a1" triangular, a2 rounded, while lobe "h" rounded. Lobe "b" with inclined distal margin.

Zenker's organ with seven rows of spines.

Female (allotype). L of LV 0.619 mm, with greatest H around middle, equalling 53% of L. RV 0.615 mm, and with greatest H 48% of L. Valves asymmetrical: left one clearly bigger than right one, overlapping it with flange dorsally (Figure 11A). Caudal margin less straight than in males, frontal more protrude than in male. Marginal zone frontally 22% of L, while caudally 16%. Greatest W (Figure 11B) equals 31% of L. Other features of carapace same as in male.

A2 4-segmented. Aesthetasc Y equals 55% of first endopodal segment (Figure 11C); y1 not

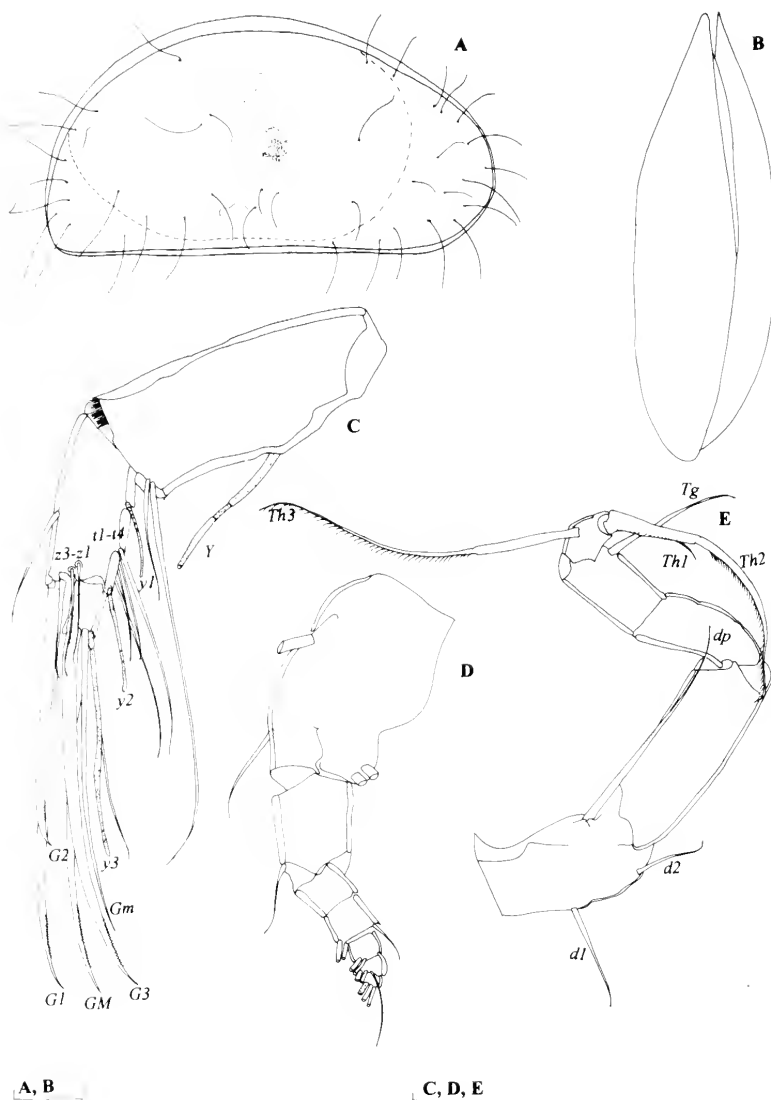


Figure 11 *Acondona memoria* gen. nov., sp. nov., allotype female (L 0.619 mm): A – carapace, external view from right side; B – carapace, dorsal view; C – A2; D – A1; E – T3. Scales = 0.1 mm.

reaching distal end of penultimate segment, y2 1.8 times as long as terminal segment, while y3 4 times as long as same segment. All "t" setae on posterior side of second endopodal segment developed; while on anterior side of same segment one seta situated medially and almost reaching distal end of terminal segment. Seta z1 more claw like, while z2 and z3 seta like. All z setae about two times as long as terminal segment. Claw G2 as long as first endopodal segment, G1 and G3 1.4 times as long as same segment. Claw GM 1.25 times as long as first endopodal segment, while Gm slightly longer

than same segment. All claws serrated. L ratio of three endopodal segments 5 : 2.7 : 1.

Endopodite of T1 (Figure 10E) with three subequally long distal setae.

T2 (Figure 10F) with claw less serrated than in male.

T3 (Figure 11E) with three setae on basal segment.

Fu (Figure 10C) with anterior seta slightly longer than in male. Claws almost equally long, and 0.9 times as long as anterior furcal margin. Genital lobe rounded, and without any appendages.

All other morphological features same as in male.

Variability

Allotype female has one A1 identical with the male, while other A1 has deformed segments (Figure 11D). Allotype female has three setae on the basal segment of both cleaning legs. The other dissected female has two setae on one leg, as in holotype, and three basal setae on the opposite leg.

Etymology

The species name comes from the Latin noun "*memoria*"(f.), meaning memory.

DISCUSSION

According to the appearance of both carapace and soft parts, the two new species are closely related. However, they can be easily distinguished by using the following features:

1. Caudal margin is rounded in *Acondona admiratio* sp. nov., straight in *A. memoria* sp. nov.;
2. In *A. admiratio* on the female's A2 claw G2 reaches middle of other terminal claws, while in *A. memoria* same claw is much longer (well exceeding middle of the terminal claws);
3. Left prehensile palp is with more elongated finger and with seta-like subterminal sclerotized structures in *A. admiratio*, while this finger is stockier and the subterminal structures are button-like in *A. memoria*;
4. On the third thoracic limb "Tf" seta is present in *A. admiratio*, absent in *A. memoria*.
5. In the type species, *A. admiratio*, lobe "h" is wavy, while in the other species the same lobe is widely rounded; also "b" lobe is with inclined distal margin in *A. memoria*, while widely rounded in the type species.

The most unusual difference between these two species is the presence of "Tf" seta on the third thoracic limb in the type species. This character occurs in two Candoninae genera (*Paracandona* Hartwig, 1899 and *Cryptocandona* Kaufmann, 1900), and in some species of the genus *Trapezicandona* Shornikov, 1969, the latter being an example where this feature is variable within one genus (see revised diagnosis in Karanovic & Pesce, 2000). The new genus is easily distinguishable from both *Cryptocandona* and *Trapezicandona* by the L of three distal setae on the third thoracic limb, i.e. in both genera the terminal segment carries two short and one long seta, while in the new genus there are two long and one short seta. This feature has not yet been found to be variable within any of the Candoninae genera. *Acondona* gen. nov. is easily distinguishable from the genus *Paracandona* by the appearance of prehensile palps (almost symmetrical in *Paracandona*), and by the general appearance of the carapace (rectangular, and strongly ornamented in *Paracandona*).

The presence of two "a" lobes is found in the genus *Caribecandona* Broodbakker, 1983. This genus, on the other hand, has six-segmented A1, reduced posterior furcal claw and absent posterior furcal seta. The general appearance of the hemipenis, especially the manner in which lobe "a1" is extended, is similar to that in the genera *Candona* Baird, 1835 and *Eucandona* Daday, 1900, where, in contrast to *Acondona*, the "M" process is well sclerotized, and the furcal trunk is longer in the relation to the anterior furcal claw. A flat, weakly sclerotized "M" process in *Acondona* is also characteristic of the genus *Pseudocandona* Kaufmann, 1900 but in this genus no species has two "a" lobes. It would be hard to distinguish *Pseudocandona* from the new genus by the chaetotaxy of the third thoracic limb because the two new species have different chaetotaxy of this leg, but also due to the variable number of setae on the basal segment in *A. memoria*. All *Pseudocandona* species lack "Tf" seta. There is a variable number of setae on the basal segment in *Pseudocandona albicans* (Brady, 1864), as Martens (1982) reported specimens of this species having two setae on the basal segment of the third thoracic limb. Similar variability has not been recorded for any other species of *Pseudocandona*. The systematics of the genus *Pseudocandona* is probably the most difficult as this genus has many species that reproduce exclusively parthenogenetically, so the appearance of the hemipenis, which is the only clear morphological character discriminating a large number of species, remains unknown. This genus is divided into six species groups (see Karanovic, 1999b), but is still in need of revision to resolve taxonomic problems. Despite variability in the chaetotaxy of the cleaning leg, Meisch's (1996) revision of the subfamily, based on this chaetotaxy, is shown to be useful to discriminate the many Holarctic genera in which this character remains constant.

No other genus of Candoninae can be confused with *Acondona*, as it has completely developed furca whereas this exhibits various levels of reduction (with absent posterior furcal seta, reduced or absent posterior furcal claw) in *Nanibicypis* Martens, 1992, *Danielocandona* Broodbakker, 1983, *Meischcandona* Karanovic, 2001, *Indocandona* Gupta, 1984, *Caribecandona* Broodbakker, 1983, *Cubacandona* Broodbakker, 1983, *Candonopsis* Vavra, 1891 and *Phreatocandona* Danielopol, 1978. In *Terrestricandona* Danielopol & Betsch, 1980, the terminal segment of the third limb has one sclerotized seta; *Nannocandona* Ekman, 1914 has a five-segmented A1 (seven-segmented in *Acanodna*); in the genera *Trajancandona* Karanovic, 1999, *Schellencandona* Meisch, 1996 and *Baicalocandona* Mazepova, 1976, Zenker's organ consists of six rows of spines (seven rows in *Acanodna*). The three new genera of

Candoninae recently described from Australian subterranean waters (Karanovic & Marmonier, in press) show greater similarity with the subtropical and tropical Candoninae and they are clearly different from *Acondona* which is more closely related to the Holarctic genera.

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Morphological and genetic variation in *Leggadina* (Thomas, 1910) with special reference to Western Australian populations

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Abstract – Recent collections of specimens from the Pilbara attributed to *Leggadina lakedownensis* stimulated an investigation of genetic and morphometric variation in *L. lakedownensis* and *L. forresti* to confirm the taxonomic status of these species, determine the extent of intraspecific variation, and develop useful markers for classification. Extensive analyses of both morphology and allozymes confirm the clear taxonomic separation of these two species. *Leggadina lakedownensis* shows considerably more intraspecific morphological variation than *L. forresti*, reflecting the former's much greater geographic range and ecological diversity. The mean body size of Thevenard Island *L. lakedownensis* is markedly larger than the other populations examined. Despite this morphological diversity, populations of *L. lakedownensis*, including those from mainland Pilbara and Thevenard Island, are genetically similar across their range. An individual from Queensland is genetically the most divergent but we have been unable to assess the morphological relationship of the topotypical population.

INTRODUCTION

The genus *Leggadina* has a wide distribution across mainland Australia, with two allopatric species currently recognised, *L. forresti* (Thomas, 1906) from central Australia and *L. lakedownensis* (Watts, 1976), broadly distributed across northern Australia (Figure 1). Baverstock *et al.* (1976) presented biochemical and karyotypic evidence to firmly establish the specific distinction of *L. lakedownensis*, then known only from a restricted area of northeast Queensland, from the more widely distributed *Leggadina forresti*.

Since these initial studies, many different populations of *Leggadina* have been sampled, especially in the Kimberley and Pilbara regions of Western Australia. Although some of these populations have been referred to *L. lakedownensis*, this attribution has not been critically examined. In addition, animals from Thevenard Island, off the Pilbara coast, are much larger than mainland populations of *Leggadina*, and this has led to some concern over the taxonomic status and conservation needs of this morphologically-distinctive form. Moro *et al.* (1998) examined variation in

mitochondrial DNA (mtDNA) from Western Australia and Northern Territory populations referred to *Leggadina lakedownensis* and found significant lineage divergence between the Pilbara (including Thevenard Island) and Kimberley populations of this species. On this basis they suggested that the Pilbara and Thevenard Island specimens together might represent a distinct subspecies. Moro *et al.* (1998) did not include any specimens from northeast Queensland in their analyses.

Prior to 1997, only two specimens of *Leggadina* had been collected in the Pilbara region. Since that time, thirty specimens, some with tissue for molecular analysis, have been collected during various surveys of the region. The availability of this new material has prompted us to conduct a comprehensive morphological and genetic study of *Leggadina* across its geographic range. The purposes of this study were to re-assess species boundaries in the genus using morphological and allozyme data, and to examine broader patterns of morphological and genetic variation across the range of *L. lakedownensis*.

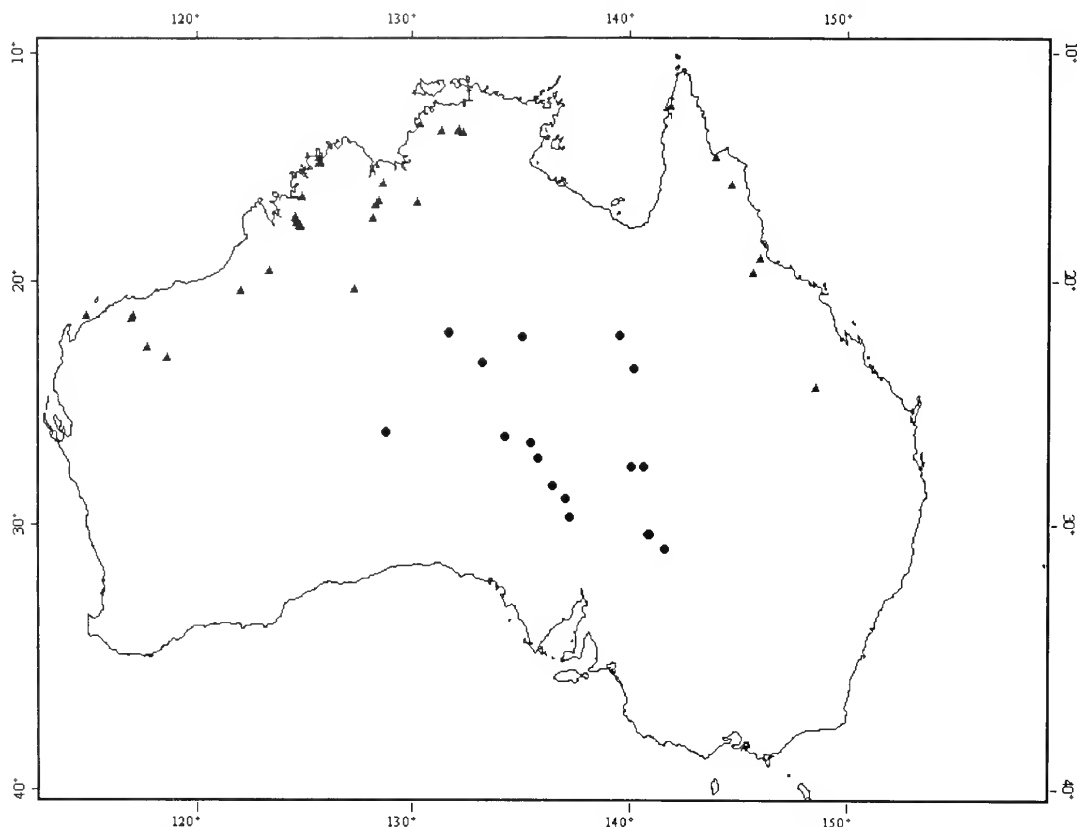


Figure 1 Distribution of *Leggadina*, with localities for specimens used in this study marked, (▲) *L. lakedownensis*, (●) *L. forresti*.

MATERIALS AND METHODS

Allozyme characterization

Genetic analysis was based on tissue samples from 16 specimens of *Leggadina lakedownensis*, aggregated into six populations according to geographic location, and 12 specimens of *L. forresti* (Appendix 1). Liver samples for allozyme electrophoresis were removed from freshly killed animals in the field or at the Western Australian Museum and immediately frozen in liquid nitrogen before being stored at -80°C . Allozyme electrophoresis of liver homogenates was conducted on cellulose acetate gels ('Cellogel') according to the methods of Richardson *et al.* (1986). The following proteins exhibited zymograms of sufficient activity to assign genotypes: aconitase hydratase (ACON, EC 4.2.1.3), aminoacylase (ACYC, EC 3.5.1.14), adenosine deaminase (ADA, EC 3.5.4.4), alcohol dehydrogenase (ADH, EC 1.1.1.1), adenylate kinase (AK, EC 2.7.4.3), albumen (ALB), carbonate dehydratase (CA, EC 4.2.1.1), diaphorase (DIA, EC 1.6.99.), enolase (ENOL, EC 4.2.1.11), fructose-bisphosphatase (FDPASE, EC

3.1.3.11), fumarate hydratase (FUM, EC 4.2.1.2), glyceraldehyde-3-phosphate dehydrogenase (GAPD, EC 1.2.1.12), lactoylglutathione lyase (GLO, EC 4.4.1.5), aspartate aminotransferase (GOT, EC 2.6.1.1), glucose-6-phosphate dehydrogenase (G6PD, EC 1.1.1.49), glycerol-3-phosphate dehydrogenase (GPD, EC 1.1.1.8), glucose-6-phosphate isomerase (GPI, EC 5.3.1.9), glutathione peroxidase (GPX, EC 1.11.1.9), glutathione reductase (GSR, EC 1.6.4.2), isocitrate dehydrogenase (IDH, EC 1.1.1.42), L-lactate dehydrogenase (LDH, EC 1.1.1.27), malate dehydrogenase (MDH, EC 1.1.1.37), "malic" enzyme (ME, EC 1.1.1.40), mannose-6-phosphate isomerase (MPI, EC 5.3.1.8), purine-nucleoside phosphorylase (NP, EC 2.4.2.1), dipeptidase (PEP-A, EC 3.4.13.), tripeptide aminopeptidase (PEP-B, EC 3.4.11.), proline dipeptidase (PEP-D, EC 3.4.13.), phosphoglycerate mutase (PGAM, EC 5.4.2.1), phosphogluconate dehydrogenase (6PGD, EC 1.1.1.44), phosphoglycerate kinase (PGK, EC 2.7.2.3), phosphoglucomutase (PGM, EC 5.4.2.2), pyruvate kinase (PK, EC 2.7.1.40), superoxide dismutase (SOD, EC 1.15.1.1), and triose-phosphate

isomerase (TPI, EC 5.3.1.1). The nomenclature for designating allozymes and multiple loci follows Adams *et al.* (1987).

A phylogenetic analysis using all specimens from both species was undertaken by constructing a neighbor-joining tree (Saitou and Nei, 1987) of Nei (1978) unbiased genetic distance. Because the populations of *L. lakedownensis* could potentially be interbreeding we also investigated their genetic relationships by a principal coordinates analysis (Gower, 1966) using the Cavalli-Sforza and Edwards (1967) arc distance matrix which is Euclidean. These analyses were carried out using Genstat (2000), Biosys-1 (Swofford and Selander, 1989) and Mega version 2.1 (Kumar *et al.*, 2001).

Morphological characterization

Morphological analysis was based on 132 specimens, of which 108 were attributable to

L. lakedownensis and aggregated into eight geographic populations, and the remainder (24) spread across most of the geographic range of *L. forresti* (Appendix 2). Skulls of *L. lakedownensis* from Queensland were not available for measurement until after the morphological analysis was completed. From the analysis, the significance of the length of the upper molar row was realised and then these measurements of the Queensland specimens were taken, though this group was not used in any multivariate statistical analyses. Skulls from Fowlers Gap and Innamincka (SAM13633, SAM10170) identified as *L. forresti* by Baverstock *et al.* (1976) using karyotypic and biochemical analyses were included herein, as were skulls from Oodnadatta, Birdsville, MacDonald Ranges and Southwest Mann Range (M21623, M21762, M21786, M6344, and M6345), also identified as *L. forresti* by Watts (1976) using morphology.

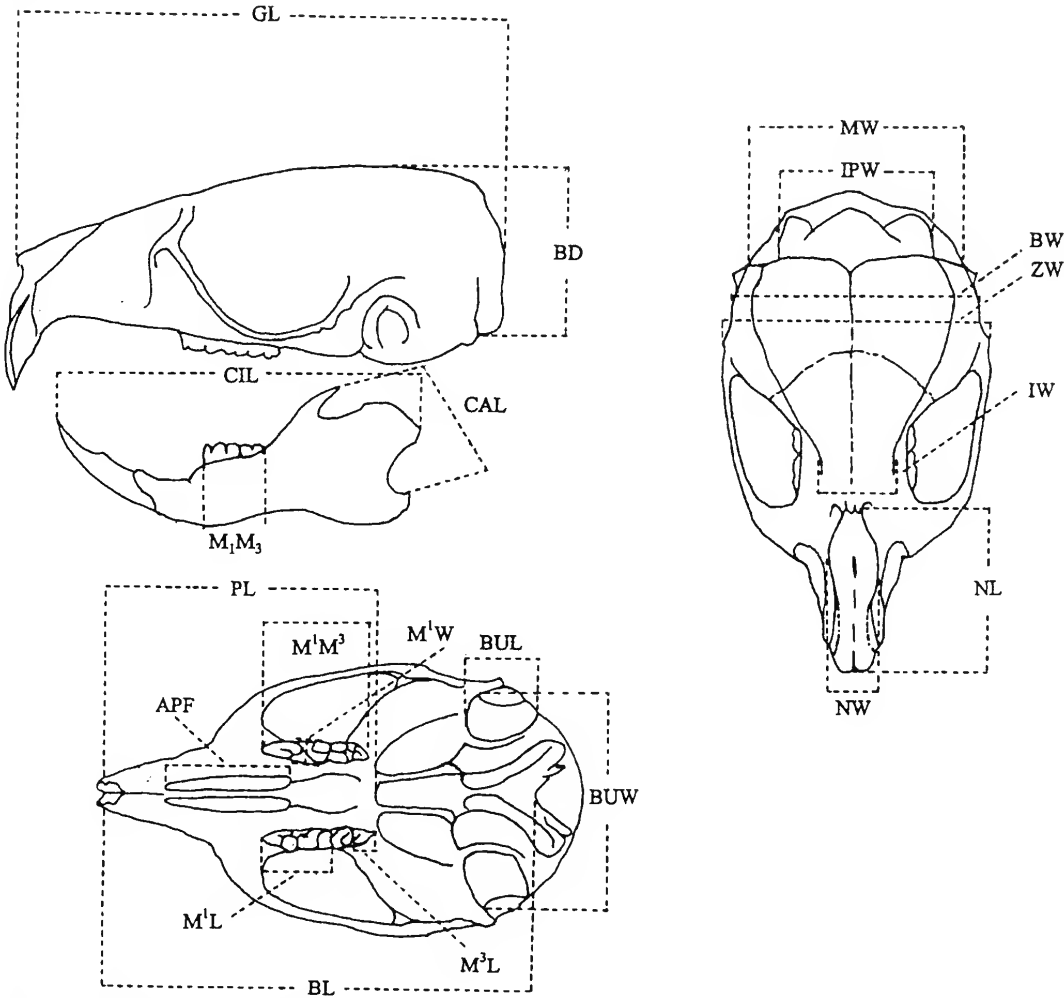


Figure 2 Skull measurement points.

Twenty measurements of skull, dentary and dental characters and six measurements of external characters (Figure 2) were recorded to the nearest 0.01mm using digital callipers. The measurements were GL, greatest skull length; BD, braincase depth; IPW, interparietal width; BW, braincase width; ZW, zygomatic width; IW, interorbital width; NL, nasal length; NW, nasal width; MW, mastoid width; BUW, width across bullae; BL, basal skull length; M¹L, upper molar 1 length; M³L, upper molar 3 length; M¹W, upper molar 1 width; M³M¹L, length of upper molar row; APF, anterior palatal foramen length; PL, palatal length; CIL, dentary condyle to tip of incisor; CAL, tip of coronoid process to posterior edge of angular process; M₁M₃L, lower molar row length. The external measurements were HV, head to vent; TV, vent to tail tip; TAILW, tail diameter measured close to body; PESW, width of pes at hallux; PESL, pes length; EARL, ear length.

M¹L was not measured during this study because its significance in differentiating between *L. lakedownensis* and *L. forresti* was not appreciated at the time of measurement, it was later calculated as M¹M¹L – M¹L – M³L.

Individuals were categorised into three age groups, mature, adult and juvenile according to the extent of tooth-wear and fusion of cranial sutures; mature – extensive tooth wear and sutures fused, adult – some tooth wear and most sutures fused and juveniles – tooth eruption, no tooth wear and sutures unfused. Age was confirmed by examination of the external reproductive status of the animal, fully descended testes or nipple development representing adults and minimal testes descent and button nipples representing juveniles. Three individuals were classified into juvenile and were excluded from all analyses. Appendix 3 lists summary statistics for 20 skull and 6 external variables in *L. lakedownensis* (grouped by geographical region) and *L. forresti*, (all localities pooled).

Initially, we used multiple regressions to investigate and remove any effects of age and sex before further multivariate analyses. These analyses also permitted the detection of statistical outliers and non-normality. For *L. lakedownensis*, each character was regressed on sex, age and locality, and the interactions between these factors. The interactions were examined first because they test for the inter-dependence of the three factors. CAL was the only cranial variable that had a significant interaction (between age and locality). This was a consequence of mean differences between the adults and mature age classes varying between localities. There was also a significant two-way interaction for TAILW ($p < 0.01$); there was no obvious fat storage in tails. These two variables were not used in any further multivariate analyses. Four variables showed statistically significant sexual dimorphism

at the 5% level of significance (see results) and most variables revealed statistically significant differences between age classes and between localities. We therefore used the estimates of the regression coefficients to remove the age and sex differences while retaining the inter-locality variation. Male and female values were adjusted to the mean of the two sexes, and mature and adult values to the mean of these two age classes. For *L. forresti*, there were not enough individuals of both sexes and each age group to test for interactions or reliably estimate main effects, so sexual dimorphism and age differences in this species were corrected by using the regression estimates made from *L. lakedownensis*. All analysis were repeated with *L. forresti* variables corrected for sex and age effects using regression estimates made from *L. forresti* and results were unchanged.

Canonical variate analysis (discriminant analysis) was used to determine the multivariate relationships between groups. Where a subset of characters was required, they were selected by sequential multivariate analysis of variance, using backward elimination and Wilks' lambda as the selection criteria. All statistical analyses were carried out using Genstat (2000).

RESULTS

Interspecies comparison

Allelic variation was observed at 24 of the 44 putative genetic loci examined (Table 1). The genetic data unequivocally diagnosed *L. lakedownensis* from *L. forresti*, with fixed differences at seven loci (*Acon1*, *Enol*, *Fdp*, *G6pd*, *Got1*, *Gsr*, and *Mdh2*) and major differences in allele frequency at another three loci (*Adh1*, *Gda*, and *Sod*). The unbiased Nei Distance between the species is about 0.28, indicating marked genetic differentiation (Table 2 and Figure 3). In contrast, regional populations of *L. lakedownensis* showed minimal differentiation, with no pairwise Nei Distance greater than 0.033 (Table 2), and only one locus showed any evidence of genetic heterogeneity (ie. a deficiency of heterozygotes) in *L. forresti* (*Ada*, data not shown).

The initial morphological appraisal examined the relationship between *L. lakedownensis* and *L. forresti* by canonical variate analysis of cranial measures to confirm the specific status of these taxa. While there is no overlap in the distribution of the two species on the canonical variate, two *L. lakedownensis* are positioned closer to the *L. forresti* centroid than their own species and so are incorrectly allocated to the wrong species (Figure 4). Because the sample size of *L. forresti* was small, only five traits, selected by backward elimination, were used in this analysis. The canonical variate is a contrast of upper molar 1

Table 1 Sample size for genetic analysis (N), putative allele frequencies at 24 variable loci, and mean heterozygosity (H) in 6 populations of *L. lakedownensis* and in *L. forresti*. The following 20 loci were invariant:– *Ak1*, *Ak2*, *Alb*, *Fum*, *Gapd*, *Glo*, *Gpd*, *Gpi*, *Gpx*, *Idhl*, *Ldhl*, *Ldh2*, *Mdhl*, *Me*, *Np*, *PepA1*, *PepB*, *Pgk*, *Pgm1*, and *Tpi*.

Locus	Allele	<i>L. lakedownensis</i>						<i>L. forresti</i>
		Pilbara	Thevenard Island	Mitchell Plateau	Lissadell	Kakadu	Queensland	
N		6	1	3	2	3	1	12
<i>Acon1</i>	a	–	–	–	–	–	–	1.00
	b	1.00	1.00	1.00	1.00	1.00	1.00	–
<i>Acon2</i>	a	–	–	–	–	–	–	0.04
	b	1.00	1.00	0.83	1.00	1.00	1.00	0.88
	c	–	–	0.17	–	–	–	0.08
<i>Acyc</i>	a	–	–	0.17	–	–	–	0.04
	b	0.92	1.00	0.83	0.75	0.67	1.00	0.92
	c	0.08	–	–	0.25	0.33	–	0.04
<i>Ada</i>	a	1.00	1.00	1.00	1.00	1.00	1.00	0.42
	b	–	–	–	–	–	–	0.50
	c	–	–	–	–	–	–	0.08
<i>Adhl</i>	a	–	–	–	–	–	–	0.88
	b	1.00	1.00	1.00	1.00	1.00	1.00	0.12
<i>Adh2</i>	a	0.08	–	–	–	–	–	–
	b	0.92	1.00	1.00	0.75	0.83	1.00	1.00
	c	–	–	–	0.25	0.17	–	–
<i>Ca</i>	a	0.17	–	–	–	–	–	0.12
	b	0.83	1.00	1.00	1.00	1.00	1.00	0.88
<i>Dia</i>	a	1.00	1.00	1.00	1.00	1.00	1.00	0.92
	b	–	–	–	–	–	–	0.08
<i>Enol</i>	a	–	–	–	–	–	–	1.00
	b	1.00	1.00	1.00	1.00	1.00	1.00	–
<i>Fdp</i>	a	–	–	–	–	–	–	1.00
	b	1.00	1.00	1.00	1.00	1.00	1.00	–
<i>G6pd</i>	a	1.00	1.00	1.00	1.00	1.00	1.00	–
	b	–	–	–	–	–	–	1.00
<i>Gda</i>	a	–	–	–	–	–	–	0.88
	b	1.00	1.00	1.00	1.00	1.00	1.00	0.12
<i>Got1</i>	a	–	–	–	0.50	–	–	1.00
	b	1.00	1.00	1.00	0.50	1.00	1.00	–
<i>Got2</i>	a	1.00	1.00	1.00	1.00	1.00	1.00	0.96
	b	–	–	–	–	–	–	0.04
<i>Gsr</i>	a	0.08	–	–	–	–	–	–
	b	–	–	–	–	–	–	1.00
	c	0.92	1.00	1.00	1.00	1.00	1.00	–
<i>Idh2</i>	a	0.92	1.00	1.00	1.00	1.00	1.00	1.00
	b	0.08	–	–	–	–	–	–
<i>Mdh2</i>	a	–	–	–	–	–	–	1.00
	b	1.00	1.00	1.00	1.00	1.00	1.00	–
<i>Mpi</i>	a	–	–	–	–	–	–	0.08
	b	1.00	1.00	1.00	1.00	1.00	1.00	0.92
<i>PepA2</i>	a	–	–	0.17	0.25	–	–	–
	b	1.00	1.00	0.83	0.75	1.00	1.00	1.00
<i>PepD</i>	a	–	–	0.33	–	–	–	–
	b	1.00	1.00	0.67	1.00	1.00	1.00	1.00
<i>Pgam</i>	a	–	–	–	–	–	–	0.04
	b	1.00	1.00	1.00	1.00	1.00	1.00	0.96
<i>6PgD</i>	a	–	–	–	0.25	0.67	–	0.75
	b	1.00	1.00	1.00	0.75	0.33	0.50	0.25
	c	–	–	–	–	–	0.50	–
<i>Pk</i>	a	1.00	1.00	1.00	1.00	1.00	–	1.00
	b	–	–	–	–	–	1.00	–
<i>Sod</i>	a	–	–	–	0.25	–	–	1.00
	b	1.00	1.00	1.00	0.75	1.00	1.00	–
H		0.022	0.000	0.035	0.072	0.032	0.023	0.058

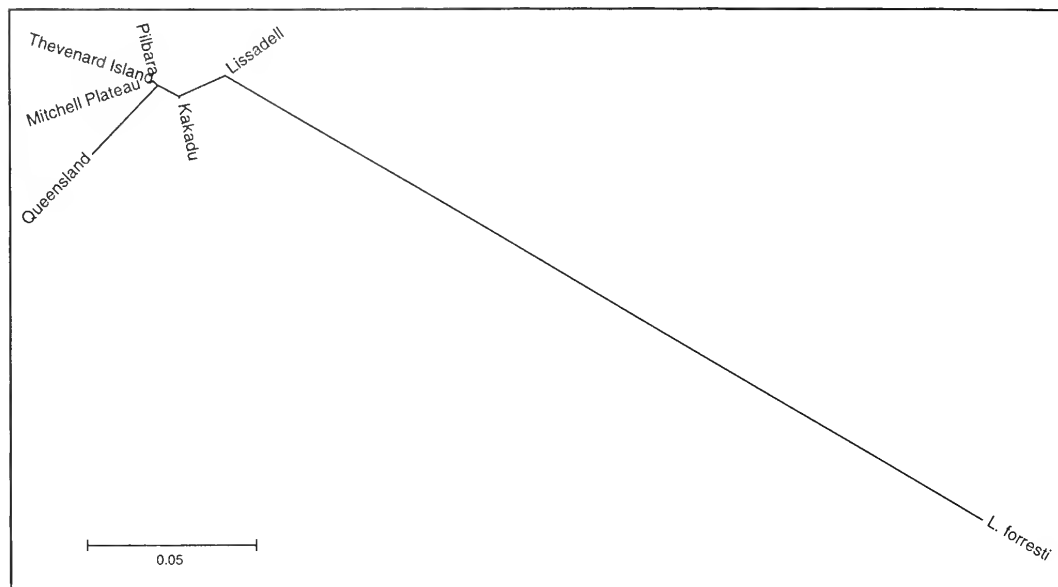


Figure 3 Neighbor-joining tree based on unbiased Nei genetic distance between six populations of *L. lakedownensis* and *L. forresti*.

Table 2 Genetic distances amongst populations of *L. lakedownensis* plus *L. forresti*. Nei unbiased distance at bottom left and Cavalli-Sforza and Edwards arc distance above and right.

	Pilbara	Thevenard Island	Mitchell Plateau	Lissadell	Kakadu	Queensland	<i>L. forresti</i>
Pilbara	–	0.069	0.115	0.142	0.122	0.182	0.481
Thevenard Island	0.000	–	0.092	0.135	0.116	0.169	0.481
Mitchell Plateau	0.002	0.001	–	0.150	0.147	0.192	0.486
Lissadell	0.003	0.003	0.002	–	0.112	0.215	0.447
Kakadu	0.010	0.011	0.011	0.001	–	0.200	0.473
Queensland	0.030	0.029	0.031	0.031	0.033	–	0.507
<i>L. forresti</i>	0.278	0.278	0.285	0.236	0.266	0.308	–

length (M/L) with the other four traits (Table 3). An equivalent analysis using five external measures revealed poor separation of the two species. Furthermore, 20 of 78 *L. lakedownensis* and one of eight *L. forresti* specimens were incorrectly allocated.

Geographic variation within *L. lakedownensis*

Principal coordinates analysis of the six *L. lakedownensis* populations revealed three genetic

clusters, namely (a) Queensland, (b) Lissadell and Kakadu, and (c) the Pilbara, Thevenard Island and Mitchell Plateau populations (Figure 5). This outcome can be seen in the genetic distance values, with minimal genetic differentiation between the three Western Australian populations and between the two Northern Territory populations (all Nei Distances < 0.003, Table 2).

Multiple regressions of skull and external measurements revealed that only four variables

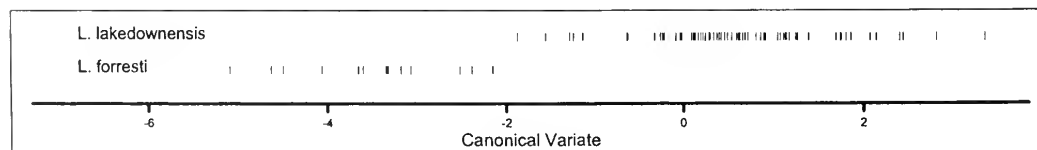


Figure 4 Plot of individuals on the canonical variate discriminating *L. lakedownensis* and *L. forresti*.

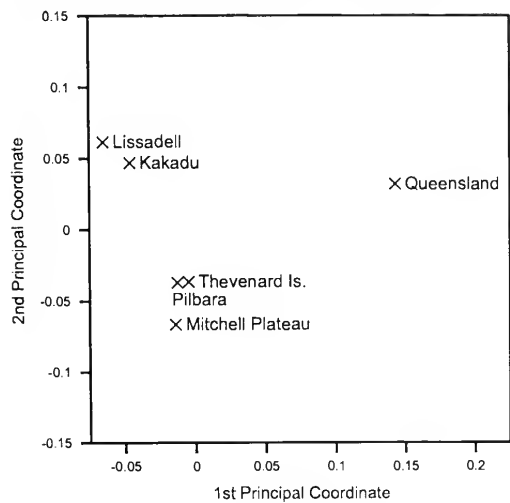


Figure 5 Scatter plot of first two components from a principal coordinates analysis of the arc genetic distance matrix for six *L. lakedownensis* populations.

Table 3 Correlations between original cranial measures and canonical variate for discriminant analysis of *L. lakedownensis* and *L. forresti*.

Trait	Correlation
BD	-0.43
BL	-0.35
M ¹ L	0.36
M ¹ M ¹ L	-0.12
CIL	-0.12

showed statistically significant sexual dimorphism ($0.01 < p < 0.05$ for all four variables). The male MW average was 0.16mm less than females; male BUW average was 0.15mm less than females; and males had a broader and shorter pes compared to females (PESW 0.19 larger and PESL 0.48 smaller). Most morphometric variables revealed statistically significant differences between age classes and between localities. All variables except APF showed statistically significant differences between localities, most at the 0.001 level. Individuals of *L. lakedownensis* from Thevenard Island and Pilbara mainland localities were larger than individuals from every other locality (Appendix 3).

Canonical variate analysis using cranial measures for the seven localities revealed the Pilbara and Thevenard island populations clustered separately from the other five locations in northern Australia (Figure 6). This analysis was based on five traits selected by backward elimination, but essentially the same results were obtained using all 19 cranial measures or forward selection of the five best (which produced four of the same traits as

Table 4 Correlations between cranial measures and the first and second canonical variates (CV 1 and CV 2) for seven *L. lakedownensis* localities.

Trait	CV 1	CV 2
BUW	0.71	-0.33
BL	0.53	0.24
M ¹ L	0.30	0.26
M ¹ W	0.74	0.57
CIL	0.38	0.36

Table 5 Correlations between external measures and the first and second canonical variates (CV 1 and CV 2) for seven *L. lakedownensis* localities.

Trait	CV 1	CV 2
HV	0.21	-0.28
TV	0.79	-0.54
PESW	0.38	0.43
PESL	0.66	0.46
EARL	0.13	0.31

backward selection). The first two canonical variates accounted for 73% and 17% of the between group variance (Table 4). The uniformly positive correlations between the five traits and the first canonical function show that this is largely a size discriminator, accounting for the separation of the Pilbara and Thevenard Island populations from the others on this axis. The second canonical variate is a contrast of width across bullae and the other four traits, especially width of M¹.

A parallel analysis using the five external features clearly separated the Thevenard Island population

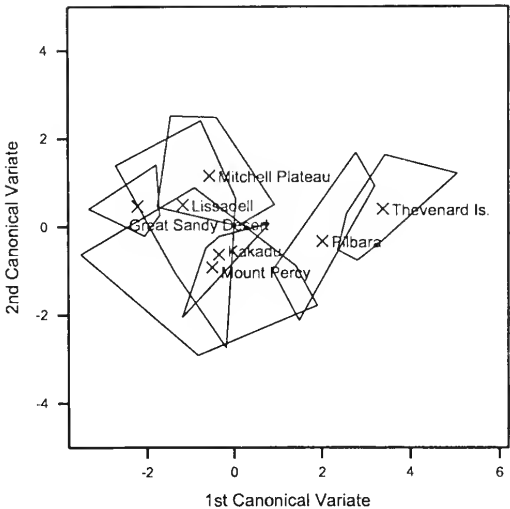


Figure 6 Plot on the first two canonical variates, using skull variables, of seven *L. lakedownensis* populations showing group centroids and polygons enclosing the range of individuals.

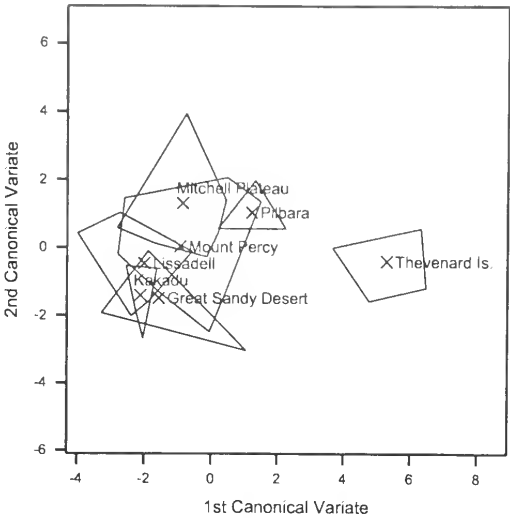


Figure 7 Plot on the first two canonical variates, using external variables, of seven *L. lakedownensis* populations showing group centroids and polygons enclosing the range of individuals.

from the others on the first canonical variate (Figure 7). This axis accounts for 85% of the between-group variation and is positively correlated with all measures (Table 5), this reflects the large size of the Thevenard Island animals, particularly in regard to the length of the tail-vent and pes.

Morphological variation in *L. lakedownensis* and *L. forresti*

Skull and teeth

Differences in skull and tooth morphology of *L. lakedownensis* and *L. forresti* are summarised in Table 6. Figures 8a–c, are dorsal, ventral and lateral photographs of skulls of *L. lakedownensis*, the smaller skull, M16906 and *L. forresti*, the larger skull, M6352. Both species appear quite variable, with especially marked geographic variation in the former species. The molar structure of both species is very similar with variation in the relative size of individual cusps and teeth rather than in their overall shape. From the canonical variate analysis, the variables BD, BL, M¹L, M¹M¹L, CIL were the most significant in diagnosing the two species; these

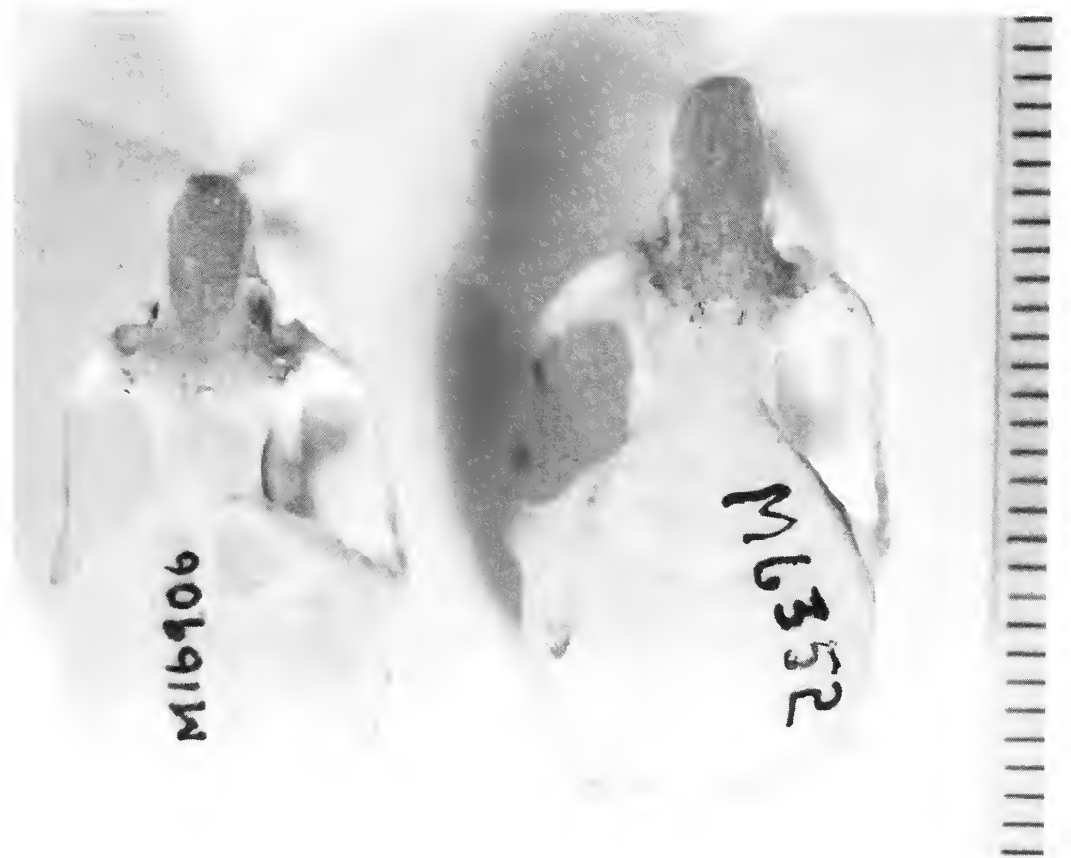


Figure 8a Dorsal view of *L. lakedownensis*, left, M16906 and *L. forresti*, right, M6352.

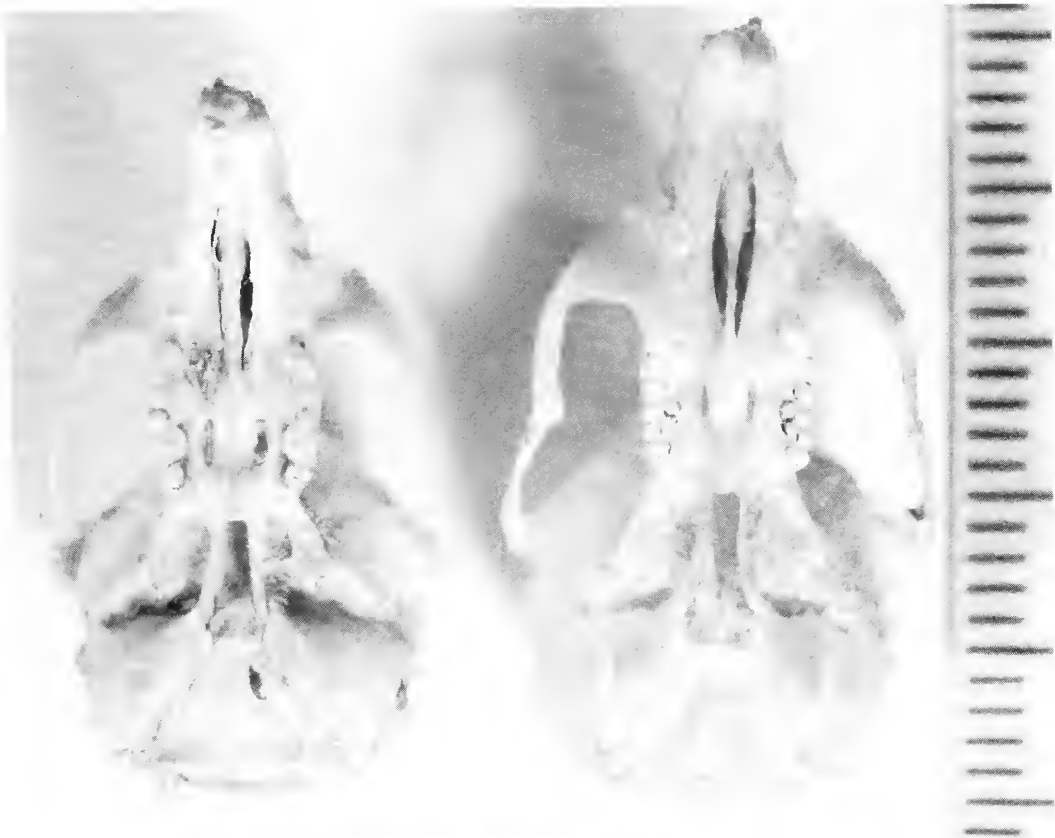


Figure 8b Ventral view of *L. lakedownensis*, left, M16906 and *L. forrestii*, right, M6352.

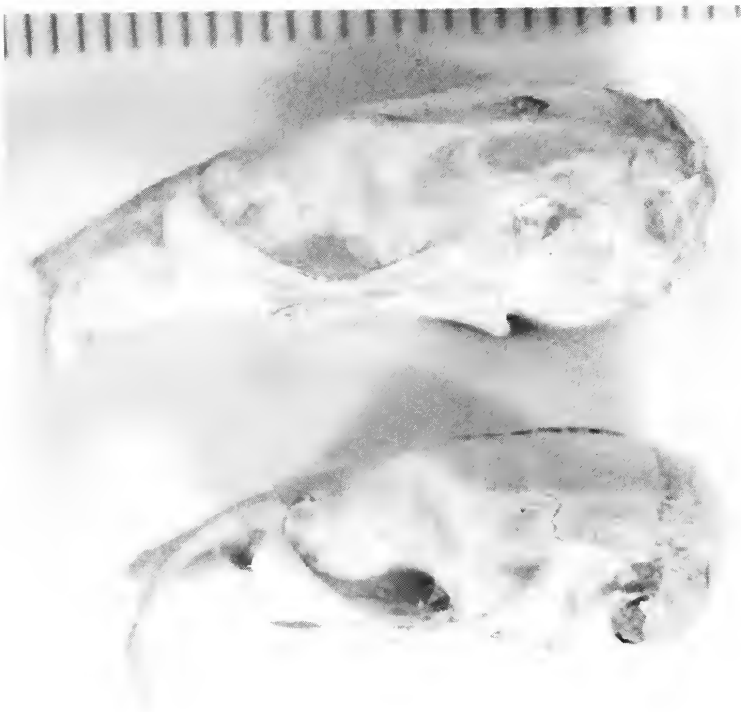


Figure 8c Lateral view of *L. lakedownensis*, below, M16906 and *L. forrestii*, above, M6352.

Table 6 Skull character differences between *L. lakedownensis* and *L. forresti*.

<i>L. lakedownensis</i>	<i>L. forresti</i>
Upper incisor sometimes proodont	Upper incisor not proodont
Rostrum shorter, broader	Rostrum longer, narrower
Braincase "square" dorsally	Braincase "round" dorsally
Braincase shallower	Braincase deeper
Basicranium shorter (except for Thevenard Island animals)	Basicranium longer
Occipital surface of skull relatively flat, with weak nuchal crest	Occipital surface of skull with distinct bulge in supracoccipital region, nuchal crest well-developed
Nasal bone stops short of incisor	Nasal bone usually overlaps incisor
Bullae wider, longer, flatter	Bullae shorter, narrower, more inflated
M ¹ L generally longer	M ¹ L generally shorter
M ¹ anterior cingulum long	M ¹ anterior cingulum short
M ² shorter relative to M ¹	M ² longer relative to M ¹
M ₁ longer	M ₁ shorter
Dentary angular process large	Dentary angular process finer
Condyle to tip of incisor generally shorter	Condyle to tip of incisor generally longer

are listed as distinguishing characters in Table 6. The two species differ in several cranial and dental characteristics (Tables 6 and 7). One particularly diagnostic feature is the relative length of M¹ to M² (M¹ is relatively longer in *L. lakedownensis*). This reflects the relatively greater development of the M¹ anterior cingular cuspule of *L. lakedownensis*, which approximates cusp t1 in bulk in this species but is much smaller than t1 in *L. forresti*. This difference is reflected in a different overall crown outline for the M¹, with a strongly L-shaped anterolingual inflection in *L. lakedownensis* and a more gently concave inflection in *L. forresti*. Variation in cingular morphology is also observed within *L. lakedownensis*. In Kimberley specimens of *L. lakedownensis* and in *L. forresti* the anterior cingulum extends posteriorly around the lingual face of cusp t1. In contrast, in Pilbara and Thevenard Island specimens, the cingulum terminates on the anterior face of cusp t1.

Across the range of *L. lakedownensis* the incisive foramina only rarely widen posteriorly (Watts,

1976), rather than narrowing as is usual in *L. forresti* and there is only rarely a notch on the upper incisor (Grahame Medlin, pers comm.). No notches on the incisor have been observed in *L. forresti*.

The skull morphology of *L. lakedownensis* is variable across its geographic range, with the upper incisor usually proodontic in Kimberley populations and only occasionally in others; the Pilbara and Thevenard Island animals have larger skull, dental and dentary characters than other populations; and the accessory cusp in the Thevenard Island animals is not as elongated as in other groups.

Externals measurements

Mean values of external characters in *L. forresti* are larger than those of all *L. lakedownensis* populations except Thevenard Island, where the animals approach the size of *L. forresti* (Appendix 3). An exception is mean ear length which distinguishes the two species absolutely. Pes of *L. forresti* are not significantly wider than *L. lakedownensis*, contrary to

Table 7 Table of means and ratios of M¹ and M² for adult male and female *L. forresti* and *L. lakedownensis*.

	<i>L. forresti</i>			<i>L. lakedownensis</i>		
	M ² L	M ¹ L	%M ² /M ¹	M ² L	M ¹ L	%M ² /M ¹
Male Total	1.35	2.24	60.3%	1.19	2.40	49.6%
Female Total	1.40	2.20	63.6%	1.23	2.40	51.3%
Pilbara male				1.33	2.48	53.6%
Pilbara female				1.29	2.53	50.1%
Thevenard male				1.28	2.49	51.4%
Thevenard female				1.26	2.43	51.9%
Kimberley male				1.15	2.38	48%
Kimberley female				1.21	2.37	51%
Queensland female				0.82	2.47	46%

Watts (1976). Mean tail length relative to head and body length for *L. lakedownensis* ranges from 72% in males in the Northern Territory to 91% for males in the Pilbara and 99% for females in Thevenard. For *L. forresti* the mean values are 81% for females and 83% for males.

Pelage and footpads

Unlike *L. forresti*, *L. lakedownensis* is variable in pelage colour, with the palest being Queensland specimens and the darkest being from the Pilbara. *L. forresti* is more rufous dorsally and it has a pure white belly. *L. lakedownensis* is more mouse-like (greyish) in colour overall, with only Queensland and Great Sandy Desert specimens having a white to cream coloured belly, though never as starkly white as in *L. forresti*. The tails of *L. forresti* are generally hairier in appearance than those of *L. lakedownensis*, probably because the hairs are longer in *L. forresti* rather than being more numerous per scale. In general the tail of both species is bicoloured, with the upper part similar in colour to the dorsal fur and the lower part paler, similar in colour to the ventrum fur. Tails of *L. lakedownensis* range from only slightly bicoloured to distinctly bicoloured. In general the pes of both species are cream to white, with the hair on the feet usually the same colour as the ventral hair.

The pattern of pedal variation in the two species is the same although there is some individual variation. For example, the lower pad under the hallux, (the post hallucal pad) is sometimes missing or very indistinct in both species.

Overall, *L. forresti* has a more chestnut dorsal appearance and stark white ventrally. Dorsally, base 50% is dark grey with upper half, buff; ventrally, snow white. Tail with almost no bicolor and some tails hairier than others.

The pelage of *L. lakedownensis* varies across its geographic range. In the Kimberley, at the Mitchell Plateau the dorsum is grey with chestnut tips; the ventrum is grey with chestnut tips; the tail is bicoloured, pale below, brownish above; and the footpads are tiny, sometimes with one indistinct. At Mt Percy, the dorsal fur is chestnut tipped (50% to 33 % of length) over grey; the ventrum is cream; the tail is slightly bicoloured, brown above, cream below; and the footpads are the same as for the Mitchell Plateau population. At Lissadell the dorsal fur is chestnut tipped (33 % of length) over grey; the ventrum is white to creamy with a little grey; the tail is slightly bicoloured to unicoloured; and the footpads are the same as for Mitchell Plateau specimens.

In the Pilbara region, the Thevenard Island specimens have a dorsum that is either chestnut (33%) over brown or all chestnut; the ventrum is either brown with the tip cream or is totally cream; the tail is unicoloured or weakly bicoloured; the

footpads are similar in pattern to other *L. lakedownensis* and variable. At Tom Price the dorsum is chestnut (33%) over grey but with an additional grey tip; the ventrum is grey/cream; the tail is bicoloured, dark grey above, paler below. At Millstream the dorsum is 25% chestnut over dark grey; the ventrum is chestnut/grey or mainly cream with some grey; the tail is bicoloured, grey above, pale below. At Newman the dorsum is 25% chestnut over dark grey; the ventrum is chestnut/grey; the tail is bicoloured as for dorsal and ventral fur. At West Angeles the dorsum 25% chestnut over grey; the ventrum is chestnut/grey; the tail is bicoloured as for the dorsal and ventral fur.

In the Great Sandy Desert the dorsum is almost entirely chestnut; the ventrum almost entirely white; the tail is bicoloured, cream below and pale brown above; the footpads are very small – the post hallucal pad is indistinct.

In Queensland specimens the dorsum ranges between all chestnut to chestnut (50%) over dark grey, through to chestnut (50%) over pale grey; the ventrum ranges from all white to cream; the tail ranges from slightly bicoloured to distinctly bicoloured; and the footpads range from a small indistinct post hallucal pad to distinct post hallucal pad.

In the Northern Territory the dorsum ranges from chestnut (50%) over dark grey with to (50%) chestnut over pale grey; the ventrum ranges from white (66%) over dark grey to white (66%) over pale grey; the tail ranges from slightly bicoloured to distinctly bicoloured; and the footpads range from small indistinct post hallucal pad to distinct post hallucal pad.

DISCUSSION

Prior to 1997, only two specimens of *Leggadina* had been collected from the Pilbara region. However, in the past five years, various faunal surveys by environmental consultants and government scientists have seen some thirty additional specimens collected and lodged in the Western Australian Museum, with other individuals marked and released. It appears, therefore, that *L. lakedownensis* is more widespread and common than previously thought, and perhaps undergoes periods of both population increase and scarcity (Stuart Anstee, pers.com).

A previous study of genetic variation within *Leggadina* (Baverstock *et al.* 1976) examined the karyotype and variation at sixteen allozyme loci, with *L. lakedownensis* represented by only three specimens from Queensland. Using a more geographically diverse range of specimens and many more allozyme loci, this study confirms that the level of genetic differentiation between *L. lakedownensis* and *L. forresti* is substantial and falls

well beyond the range of intra-specific mammalian variation (Nei 1987). Furthermore, the mean heterozygosity within each of the populations accords well with other mammalian species (Nei 1987). The single specimen sampled from the Thevenard Island population was homozygous at all loci; this may reflect genetic drift in an isolate or it may be due to sampling error.

This study indicates that genetic differentiation, as measured by 44 nuclear loci, is minimal between populations of *L. lakedownensis* across its range. Moro *et al.* (1998) reported mtDNA differences between populations of *L. lakedownensis* and noted that the Pilbara and Thevenard Island populations showed the greatest divergence from the other regions. This dichotomy is not supported by the allozyme data, which instead group all three Western Australian populations together to the exclusion of those to the east, and suggest that the Queensland population (albeit represented by a single specimen) is the most differentiated. The Pilbara/Thevenard Island animals are considerably larger than all others; indeed, the Thevenard Island animals in particular are so large that some have suggested that they may represent either a distinct species or a geographic outlier of *L. forresti*. Neither of these suggestions are supported by any of the three data sets now available. Of course, it might still be argued that the Pilbara/Thevenard Island populations warrant recognition as a distinct subspecies, but the overlap in sizes between the Pilbara and Mount Percy populations, coupled with the lack of any allozyme differentiation in Western Australia, leads us to conclude otherwise.

The skulls of *L. lakedownensis* and *L. forresti* can be distinguished using the ratio of M¹L/M¹L and on the degree of elongation of the anterior cingulum on M¹ in *L. lakedownensis*. Externally, *L. forresti* can easily be distinguished from *L. lakedownensis* by its more rufous dorsal and pure white venter. *L. forresti* also has longer ears than any population of *L. lakedownensis*.

The skulls of *L. lakedownensis* morphologically are quite variable including features that might normally be expected to distinguish murine species (e.g. incisor orientation). However, this species has the largest geographic distribution of the two, and therefore experiences a wide variety of habitats and climates. The Thevenard Island population has a much larger body size than the other populations. Pelage pattern also shows marked differences between populations and, together with body size, can be used to confidently assign animals into their appropriate geographic region. *L. forresti* has a more discrete distribution in central Australia, and this appears to be reflected in the morphologically more homogenous nature of this species.

According to Reid and Morton (1995), the

distribution of *L. forresti* extends further into Queensland and New South Wales than has been surveyed herein. Accordingly, we may not have fully characterized the genetic and morphological diversity present in this species. Based on present knowledge of extant populations, the geographic distributions of the two *Leggadina* species are clearly disjunct, permitting species identification in the field to be predicted from an animal's geographic location. Fortunately, sufficient differences in their external morphology are available to make this a method of convenience rather than one of need.

In summary, the morphological and allozyme data presented herein demonstrate that the genus *Leggadina* comprises two allopatric species, *L. lakedownensis* and *L. forresti*. These can be diagnosed using both morphological and genetic criteria. Of the two, *L. lakedownensis* displays more geographic variation than *L. forresti*, but this variation is nevertheless insufficient to warrant subspecific status for any regional populations.

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Appendix 1 Collection data for specimens used in genetic analyses. Prefixes for registration numbers are SAM – South Australian Museum; WAM – Western Australian Museum; NTM – Museum of the Northern Territory; JM – Queensland Museum; ABTC – Australian Biological Tissues Collection

L. forresti

Northern Territory

MacDonnell Ranges, 23°26'S, 134°44'E, ABTC24040

South Australia

Yelpawaralinna Water, 27°05'S, 138°41'E, SAM M17585; Koonchera Waterhole, 23°43'S, 139°31'E, SAM M17570; Dulkaninna – 28°59'S, 138°33'E, SAM M17835, 28°57'S, 138°38'E, SAM M17834; Dalarinna Hill, 29°41'S, 138°41'E, SAM M17847; North Olary Plains–32°02'S, 140°54'E, SAM M18869, 30°28'S, 140°57'E, SAM M18876; Todmorden Station, 27°22'S, 134°31'E, SAM M19214; Nilpinna Station, 28°13'S, 135°25'E, SAM M19251; Pitpalyatjara, 26°10'S, 129°09'E, SAM M18343-4

L. lakedownensis

Northern Territory

Litchfield N.P., 13°29'S, 130°42'E, NTM U4198; Bradshaw Stn, 15°23'S, 130°09'E, ABTC30310; Gregory Creek, 15°19'S, 131°08'E NTM U386; Kakadu, 12°40'S, 132°50'E, ABTC28413-4

Western Australia

Kimberley

Mitchell Plateau – 14°52'05"S, 125°50'45"E, WAM M21786, 14°49'15"S, 125°50'15"E, WAM M21762-3; Lissadell–15°23'S, 130°09'E, ABTC30310, 15°19'S, 130°08'E, NTM U386

Pilbara

Millstream – 21°24'49"S, 117°09'43"E, WAM M47733, 21°19'48"S, 117°11'20"E, WAM M47720-1, 21°35'S, 117°04'E, ABTC10610; Mt Tom Price, 22°44'S, 117°47'E, WAM M47829; Newman, 22°55'S, 118°43'E, WAM M47912; Thevenard Island, 21°28'S, 115°00'E, ABTC10622

Queensland

Paluma, 19°00'S, 146°01'E, JM10863

Appendix 2 Collection Data for specimens used in morphological study. Locality, geographic coordinates, sex (M male, F female) and registration number. Prefixes for registration numbers are as in Appendix 1. An asterisk beside the Museum number denotes this specimen also used in genetic analysis.

L. forresti

Northern Territory

MacDonald, 22°25'36"S, 135°07'36"E, f, NTM U2958; Oodnadatta, 24°48'00"S, 135°22'36"E, m, NTM U6352; Coorabulka, 23°44'48"S, 140°18'00"E, f, NTM U9688; Yuendumu, 22°15'00"S, 131°48'00"E, 2f, NTM U13628-9, f, NTM U13797; Hamilton Downs, 23°31'36"S, 133°16'36"E, m, NTM U13632

Queensland

Birdsville, 22°23'48"S, 139°38'48"E, 2m, NTM U6350-1

South Australia

Innaminka, 27°44'48"S, 140°46'36"E, m, SAM M10170; Embarka, 27°43'36"S, 140°08'48"E, m, SAM M11476; Ucatunna Hill, 27°24'02"S, 135°52'49", m, SAM M18514; Unducarra Hill, 26°28'32"S, 134°19'53"E, f, SAM M18545; Memory Bore, 26°42'06"S, 135°30'00"E, f, SAM M18563; Four Hills Trig, 28°30'00"S, 136°30'00"E, m, SAM M18710; Abertachna Well, 29°43'12"S, 137°20'48"E, m, SAM M18808; Emerald Spring, 29°23'00"S, 137°08'48"E, m, SAM M18816; Starvation Dam, 30°27'47"S, 140°56'48"E, m, SAM M18876; McIntyre Bore, 30°25'57"S, 140°58'26"E, m, SAM M18882

Western Australia

SW Mann Range, 26°18'00"S, 128°52'36"E, 2f, SAM M6344-5; Bell Rock, 26°18'00"S, 128°52'36"E, 2f, SAM M6347, SAM M6349

New South Wales

Fowlers Gap, 31°00'00"S, 141°42'00"E, m, SAM M13633

L. lakedownensis

Western Australia

Kimberley

Lissadell - 16°44'00"S, 128°26'36"E, 4m, WAM M16893, WAM M16869, WAM M19278-9, f, WAM M16870; 16°40'00"S, 128°23'13"E, 3m, WAM M16872, WAM M16874, WAM M16900; 16°44'00"S, 128°26'36"E, m, WAM M16893; 16°32'51"S, 128°33'30"E, m, WAM M18833; 17°37'00"S, 124°52'19"E, 3m, WAM M16904-6; Mt Percy- 17°35'54"S, 124°54'06"E, 2f, WAM M16919-20; 17°41'32"S, 124°56'03"E, m, WAM M16944, f, WAM M16945; 17°40'23"S, 124°56'03"E, 3m, WAM M16944, WAM M16950-1 2f, WAM M16945-6; 17°40'23"S, 124°56'03"E, m, WAM M16957, f, WAM M16959; 17°37'00"S, 124°52'19"E, 3f, WAM M16952, WAM M16962, WAM M16975; Barker Gorge- 17°14'15"S, 124°38'15"E, f, WAM M18553, 6m, WAM M18554-7, WAM M18559-60; Calder River, 16°19'00"S, 124°58'00"E, f, WAM M17494; Mt North, 17°29'46"S, 124°45'05"E, f,

WAM M16965; Mitchell Plateau- 14°53'59"S, 125°50'10", m, WAM M15536, 14°35'15"S, 125°45'30"E, 2f, WAM M18068-9, 2m, WAM M18070, WAM M18084; 14°47'59"S, 125°49'00"E, m, WAM M18100; 14°52'05"S, 125°50'45"E, f, *WAM M21526; 14°53'09"S, 125°48'55"E, m, WAM M21623; 14°49'14"S, 125°50'15"E, m, *WAM M21762, 2f, WAM M21752, WAM M21767; 14°50'30"S, 125°50'30"E, f, *WAM M21786; 14°52'19"S, 125°49'15"E, 3f, WAMMM22044, WAM M22090-1; Kununurra- 15°47'30"S, 128°45'30"E, m, WAM M14857; 15°46'00"S, 128°44'00"E, m, WAM M19644, f, WAM M19645; Bungle Bungle, 17°15'00"S, 128°18'00"E, f, WAM M32657; McLarty, 19°30'00"S, 123°30'00"E, m, WAM M19840; Gt Sandy Desert- 20°24'00"S, 122°08'00"E, 3m, WAM M2725, WAM M22725-6; 22°33'00"S, 122°23'00"E, m, WAM M22727; 20°20'59"S, 127°26'00"E, m, WAM M22728

Pilbara

Millstream- 21°35'59"S, 117°04'00"E, f, WAM M27011; 2m, *WAM M47720-21; Tom Price- 22°45'00"S, 117°46'00"E, m, WAM M47326, 22°49'01"S, 115°46'53"E, f, WAM M47710, 22°48'48"S, 117°47'20"E, 2f, WAM M47711-2; Chichester, 21°25'48"S, 117°10'43"E, m, *WAM M47733; Newman, 22°55'57"S, 118°43'48"E, f, *WAM M47912; Westangeles- 23°11'51"S, 118°45'48"E, m, WAM M47672, 23°11'51"S, 118°44'08"E, f, WAM M47673

Thevenard Island

Thevenard Island, 21°28'00"S, 115°00'00"E, 9m, WAM M7402, WAM M7404-6, WAM M7408-10, WAM M7412, WAM M28921, 9f, WAM M7403, WAM M7411, WAM M21296, WAM M34163, WAM M47416-7, WAM M47434-5

Queensland

Lakeland, 15°50'48"S, 144°50'48"E, 2m, JM1024, JM2874, 2f, JM1293-4; Mapoon, 11°59'48"S, 142°00'00"E, JM4030; Batavia, 12°09'00"S, 141°54'00"E, JM4031; Stonexing, 12°23'48"S, 142°00'00"E, f, JM4032; Hillgrove, 19°38'48"S, 145°43'12"E, m, JM4954; Hiddenvall, 19°00'00"S, 146°05'48"E, f, JM10863; Undurra, 18°13'12"S, 144°34'12"E, f, JM11573; Rolleston, 24°28'12"S, 148°38'48"E, f, JM11585; Williams, 14°37'12"S, 144°06'00"E, f, JM17919

Northern Territory

Pine Creek, 13°30'00"S, 131°28'12"E, f, NTM U2445; Litchfield, 13°09'00"S, 130°26'24"E, f, NTM U4198; 16°04'12"S, 130°15'00"E, m, NTM U4353; Mt Sanford, 16°35'24"S, 130°20'24"E, m, NTM U4480; Kakadu- 13°25'00"S, 132°06'00"E, f, WAM M43288, 13°29'59"S, 132°15'00"E, f, WAM M43289, 13°30'00"S, 132°35'00"E, f, WAM M43290, 13°31'00"S, 132°27'00"E, m, WAM M43291, 13°23'59"S, 132°16'00"E, m, WAM M43292

Appendix 3 Summary statistics for twenty skull and six external variables in eight populations of *Leggadina lakedownensis* and in *L. forresti*. (F = female; M = male)

Variable	Statistic	Pilbara		Thevenard Island		Great Sandy Desert		Mount Percy		Mitchell Plateau		Lissadell		Kakadu		Queensland		<i>L. forresti</i>	
		F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
GL	n	3	4	5	5	4	0	11	10	6	9	10	3	2	3	0	0	6	9
	mean	22.8	23.6	24.9	23.4	20.8		21.7	21.5	21.8	22.0	21.8	21.1	22.2	20.6			24.2	23.5
	sd	1.00	0.65	1.30	0.81	0.95		1.12	1.07	0.61	0.59	0.71	0.40	0.81	0.26			0.52	0.79
	min	21.7	22.8	23.7	22.0	19.6		19.5	20.0	21.1	21.2	20.8	20.7	21.6	20.3			23.3	22.2
	max	23.6	24.2	27.1	24.0	21.8		23.1	23.5	22.6	22.9	22.9	21.5	22.8	20.8			25.0	24.7
BD	n	3	4	5	5	4	0	12	10	6	9	10	3	2	3	0	0	6	9
	mean	7.4	7.4	7.3	7.3	6.8		7.0	7.0	7.1	6.9	7.1	6.9	7.2	7.0			7.6	7.6
	sd	0.29	0.22	0.34	0.21	0.24		0.30	0.28	0.24	0.24	0.38	0.16	0.44	0.17			0.22	0.37
	min	7.1	7.2	7.0	7.0	6.5		6.5	6.6	6.7	6.7	6.7	6.7	6.9	6.8			7.2	7.1
	max	7.7	7.7	7.9	7.5	7.0		7.4	7.7	7.4	7.4	7.8	7.0	7.5	7.1			7.7	8.1
IPW	n	3	3	5	5	4	0	11	10	6	9	10	3	2	3	0	0	6	9
	mean	8.2	8.2	8.9	8.7	7.0		7.6	7.6	7.8	8.0	7.5	7.6	8.0	7.8			8.2	8.0
	sd	0.56	0.48	0.37	0.43	0.42		0.42	0.46	0.40	0.44	0.49	0.35	0.36	0.22			0.45	0.53
	min	7.8	7.7	8.2	8.1	6.4		7.0	6.7	7.3	7.0	6.4	7.3	7.7	7.7			7.4	7.3
	max	8.8	8.6	9.2	9.3	7.4		8.5	8.4	8.5	8.4	8.1	8.0	8.2	8.1			8.7	8.7
BW	n	3	4	5	5	4	0	11	10	6	9	10	3	2	3	0	0	7	9
	mean	10.8	11.1	11.3	11.2	10.2		10.7	10.6	10.6	10.6	10.5	10.3	10.9	10.5			11.3	11.0
	sd	0.12	0.36	0.12	0.35	0.28		0.49	0.29	0.26	0.21	0.31	0.37	0.46	0.29			0.24	0.32
	min	10.7	10.8	11.1	10.7	9.8		10.0	10.2	10.1	10.3	9.8	10.0	10.5	10.3			10.9	10.5
	max	10.9	11.6	11.4	11.6	10.5		11.5	11.1	10.9	10.9	10.8	10.7	11.2	10.8			11.6	11.4
ZW	n	3	4	5	5	4	0	11	10	6	9	10	3	2	3	0	0	7	9
	mean	12.7	12.9	13.2	12.7	11.3		12.1	12.3	11.7	12.1	11.7	11.7	12.5	11.5			12.9	12.6
	sd	0.82	0.27	0.31	0.75	0.59		0.53	0.68	0.54	0.34	0.62	0.27	0.42	0.34			0.39	0.76
	min	11.8	12.6	12.9	11.6	10.7		11.2	11.2	10.8	11.6	10.4	11.4	12.2	11.1			12.2	11.8
	max	13.3	13.1	13.6	13.5	12.0		12.9	13.4	12.4	12.6	12.4	12.0	12.8	11.7			13.5	13.8
IW	n	3	4	5	5	4	0	12	10	6	9	10	3	2	3	0	0	7	9
	mean	3.5	3.8	3.9	3.9	3.5		3.4	3.4	3.5	3.5	3.4	3.4	3.5	3.5			3.7	3.6
	sd	0.22	0.17	0.14	0.08	0.17		0.15	0.14	0.16	0.18	0.21	0.10	0.12	0.02			0.20	0.21
	min	3.3	3.6	3.8	3.8	3.2		3.2	3.2	3.4	3.3	3.1	3.3	3.4	3.5			3.5	3.3
	max	3.8	3.9	4.1	4.0	3.6		3.8	3.7	3.8	3.8	3.8	3.5	3.6	3.5			4.1	3.9
NL	n	3	4	5	5	4	0	12	10	6	9	10	3	2	3	0	0	7	9
	mean	8.3	8.3	8.3	7.8	7.2		7.6	7.4	7.7	7.8	7.7	7.4	8.0	7.0			8.1	8.0
	sd	0.93	0.48	1.02	0.93	0.44		0.56	0.42	0.56	0.49	0.38	0.20	0.03	0.13			0.32	0.39
	min	7.3	7.7	6.8	6.3	6.7		6.8	6.7	6.7	7.1	6.7	7.2	8.0	6.8			7.5	7.2
	max	9.1	8.9	9.4	8.6	7.6		8.4	8.1	8.2	8.5	8.1	7.6	8.0	7.1			8.5	8.4

NW	n	3	4	5	4	4	0	12	10	6	9	10	3	2	3	0	0	7	8
	mean	2.1	2.1	2.1	2.0	1.7		1.9	1.8	1.9	1.9	1.8	1.8	1.8	1.7			2.0	2.0
	sd	0.19	0.07	0.19	0.06	0.09		0.20	0.24	0.14	0.14	0.17	0.17	0.32	0.22			0.15	0.16
	min	1.9	2.0	1.9	2.0	1.6		1.4	1.3	1.8	1.6	1.5	1.6	1.6	1.5			1.9	1.8
	max	2.2	2.1	2.4	2.1	1.8		2.2	2.0	2.2	2.0	2.0	1.9	2.0	1.9			2.3	2.3
MW	n	3	4	5	5	4	0	11	10	3	9	10	3	2	3	0	0	6	9
	mean	9.5	9.7	9.6	9.3	8.2		8.9	8.7	8.6	8.6	8.6	8.5	8.9	8.4			9.3	9.3
	sd	0.67	0.56	0.17	0.38	0.32		0.35	0.32	0.29	0.32	0.18	0.39	0.06	0.09			0.14	0.34
	min	8.8	9.3	9.4	8.7	7.9		8.3	8.3	8.4	8.1	8.4	8.1	8.9	8.3			9.0	8.8
	max	10.2	10.5	9.8	9.6	8.6		9.4	9.3	9.0	9.0	8.9	8.8	9.0	8.4			9.5	9.9
BUW	n	3	4	5	5	4	0	12	10	4	9	10	3	2	3	0	0	5	9
	mean	11.0	11.2	11.5	11.1	10.2		10.7	10.7	10.7	10.7	10.5	10.3	11.0	10.3			11.6	11.4
	sd	0.32	0.28	0.25	0.47	0.27		0.35	0.47	0.30	0.29	0.32	0.28	0.24	0.36			0.58	0.42
	min	10.7	10.9	11.3	10.4	9.9		10.0	10.1	10.4	10.3	9.9	10.0	10.8	9.9			10.8	10.7
	max	11.3	11.6	11.9	11.5	10.5		11.2	11.4	11.1	11.2	10.8	10.5	11.2	10.7			12.4	12.1
BL	n	3	3	5	4	4	0	11	10	6	8	10	3	2	3	0	0	6	9
	mean	20.1	20.9	22.0	20.9	18.3		19.5	19.2	19.6	20.0	19.5	19.0	20.3	18.5			21.6	21.1
	sd	1.48	0.57	1.48	1.21	0.87		1.06	1.24	0.79	0.59	0.70	0.16	0.80	0.55			0.43	0.86
	min	18.5	20.3	21.1	19.4	17.2		17.9	17.4	18.3	19.1	18.6	18.8	19.7	18.0			21.0	19.5
	max	21.3	21.4	24.6	22.4	19.2		21.0	21.5	20.5	20.9	20.7	19.1	20.8	19.1			22.1	22.5
PL	n	3	4	5	5	4	0	12	10	6	9	10	3	2	3	0	0	7	9
	mean	12.7	13.5	14.1	13.5	11.6		12.2	12.2	12.4	12.8	12.3	12.1	12.0	11.7			13.3	13.0
	sd	1.00	0.57	0.80	0.78	0.47		0.68	0.67	0.53	0.32	0.50	0.43	0.42	0.51			0.41	0.69
	min	11.6	12.8	13.6	12.4	11.2		11.0	11.2	11.6	12.3	11.7	11.7	11.7	11.1			12.5	11.8
	max	13.4	14.0	15.5	14.4	12.1		13.1	13.3	13.0	13.2	13.3	12.5	12.3	12.1			13.8	14.0
M'L	n	3	4	5	5	4	0	12	10	6	9	10	3	2	3	0	0	7	9
	mean	2.5	2.5	2.5	2.4	2.3		2.4	2.3	2.4	2.4	2.4	2.4	2.4	2.3			2.2	2.2
	sd	0.04	0.09	0.07	0.10	0.13		0.10	0.14	0.11	0.11	0.11	0.05	0.02	0.10			0.15	0.13
	min	2.4	2.4	2.4	2.3	2.1		2.2	2.1	2.2	2.2	2.3	2.3	2.4	2.2			2.0	2.0
	max	2.5	2.6	2.6	2.6	2.4		2.5	2.6	2.5	2.6	2.7	2.4	2.4	2.3			2.4	2.3
M'L	n	3	4	5	5	4	0	12	10	6	9	10	3	2	3	0	0	7	9
	mean	0.7	0.8	0.8	0.8	0.7		0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.6			0.8	0.8
	sd	0.05	0.09	0.03	0.04	0.09		0.07	0.06	0.07	0.07	0.05	0.06	0.06	0.06			0.07	0.07
	min	0.7	0.7	0.8	0.7	0.6		0.6	0.6	0.6	0.6	0.6	0.7	0.6	0.6			0.7	0.7
	max	0.8	0.9	0.9	0.8	0.8		0.9	0.8	0.8	0.8	0.8	0.8	0.7	0.7			1.0	0.9
M'W	n	3	4	5	5	4	0	12	10	6	9	10	3	2	3	0	0	7	9
	mean	1.5	1.5	1.6	1.5	1.4		1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4			1.5	1.4
	sd	0.02	0.11	0.04	0.07	0.05		0.05	0.07	0.09	0.06	0.05	0.04	0.04	0.07			0.06	0.05
	min	1.5	1.4	1.6	1.5	1.3		1.3	1.2	1.2	1.3	1.3	1.3	1.4	1.3			1.4	1.4
	max	1.5	1.6	1.7	1.6	1.4		1.5	1.4	1.5	1.5	1.5	1.4	1.5	1.4			1.5	1.5

Appendix 3 (cont.)

Variable	Statistic	Pilbara		Thevenard Island		Great Sandy Desert		Mount Percy		Mitchell Plateau		Lissadell		Kakadu		Queensland		<i>L. forresti</i>	
		F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
M ₁ M ₃ L	n	3	4	5	5	4	0	12	10	6	9	10	3	2	3	0	0	7	9
	mean	4.5	4.6	4.6	4.5	4.0		4.3	4.2	4.3	4.3	4.2	4.3	4.1	4.0			4.4	4.4
	sd	0.10	0.10	0.06	0.06	0.22		0.17	0.25	0.22	0.11	0.12	0.13	0.11	0.16			0.17	0.20
	min	4.4	4.5	4.5	4.4	3.8		4.0	3.9	3.9	4.2	4.1	4.1	4.0	3.8			4.1	4.1
	max	4.6	4.7	4.7	4.5	4.3		4.5	4.6	4.4	4.5	4.5	4.4	4.2	4.1			4.7	4.7
APF	n	3	4	5	5	4	0	12	10	6	9	10	3	2	3	0	0	7	9
	mean	5.2	5.1	5.6	5.2	5.3		5.0	5.1	5.3	5.4	5.1	5.5	5.2	4.7			5.2	5.4
	sd	0.53	0.53	0.46	0.52	0.30		0.52	0.39	0.31	0.16	0.35	0.08	0.29	0.43			0.22	0.52
	min	4.6	4.7	5.0	4.4	4.8		4.0	4.5	4.9	5.2	4.5	5.4	5.0	4.4			5.0	4.7
	max	5.5	5.9	6.1	5.7	5.5		5.6	5.6	5.8	5.6	5.5	5.5	5.4	5.2			5.5	6.6
CIL	n	3	4	5	5	4	0	12	10	5	9	10	3	2	3	0	0	5	9
	mean	15.5	16.4	17.0	16.2	14.6		15.1	15.3	16.0	16.2	15.3	14.9	15.9	14.6			16.0	15.9
	sd	0.62	0.66	0.74	0.87	0.61		0.84	1.04	0.42	0.55	0.70	0.33	0.71	0.57			0.41	0.70
	min	14.8	15.6	16.5	14.9	13.9		13.7	13.6	15.5	15.5	14.0	14.6	15.4	13.9			15.4	14.6
	max	15.9	17.2	18.3	17.3	15.1		16.3	17.1	16.4	16.9	16.3	15.2	16.4	15.0			16.5	16.8
CAL	n	3	4	5	4	4	0	11	9	5	8	9	3	2	1	0	0	5	7
	mean	5.8	6.0	6.0	5.8	5.1		5.5	5.7	5.5	6.0	5.4	5.3	5.9	4.8			6.3	5.7
	sd	0.55	0.60	0.36	0.57	0.47		0.44	0.68	0.18	0.50	0.29	0.15	0.11				0.26	0.21
	min	5.2	5.2	5.6	5.1	4.5		4.9	4.7	5.4	5.2	5.0	5.2	5.9	4.8			6.0	5.5
	max	6.2	6.5	6.6	6.5	5.6		6.2	6.7	5.8	7.0	5.9	5.5	6.0	4.8			6.5	6.0
M ₁ M ₃ L	n	3	4	5	5	4	0	12	10	5	9	10	3	2	3	0	0	6	9
	mean	3.6	3.8	3.8	3.8	3.3		3.5	3.4	3.4	3.5	3.4	3.3	3.4	3.4			3.6	3.6
	sd	0.10	0.14	0.21	0.16	0.16		0.19	0.18	0.20	0.12	0.10	0.21	0.11	0.13			0.09	0.10
	min	3.5	3.6	3.5	3.7	3.2		3.2	3.1	3.1	3.3	3.2	3.1	3.3	3.3			3.5	3.5
	max	3.7	4.0	4.0	4.0	3.5		3.8	3.7	3.7	3.7	3.6	3.5	3.4	3.5			3.8	3.8
HV	n	3	3	5	7	6	0	13	9	5	8	9	3	2	2	3	3	6	2
	mean	59.8	74.2	82.2	76.3	63.5		64.4	67.0	65.9	64.2	65.7	63.8	68.2	73.1			72.4	73.8
	sd	7.12	10.31	6.24	11.16	6.12		11.33	11.21	6.40	4.25	5.89	5.44	2.19	0.42			2.87	3.72
	min	51.8	62.4	77.5	56.0	56.7		50.2	52.0	55.0	57.7	60.0	60.0	66.7	72.8			70.0	70.0
	max	65.5	81.3	92.0	91.0	73.0		84.8	82.5	70.2	72.0	75.3	70.0	69.8	73.4			75.6	78.0
TV	n	3	4	5	7	6	0	13	9	5	8	8	3	2	2	3	3	6	2
	mean	56.8	56.0	75.0	76.5	52.9		52.3	51.7	51.1	51.8	49.7	53.6	52.7	54.0			44.5	47.0
	sd	3.42	7.77	2.40	4.75	7.43		4.29	5.86	3.85	4.11	4.61	0.55	3.46	1.84			4.88	10.51
	min	53.2	45.5	72.5	69.0	46.9		46.0	42.0	44.5	47.0	42.0	53.0	50.2	52.7			39.0	39.4
	max	60.0	64.3	78.6	83.4	67.0		58.3	63.0	54.6	58.4	55.0	54.0	55.1	55.3			48.3	59.0

TAILW	n	3	4	5	7	6	0	13	9	5	8	9	3	2	2	3	3	6	2
	mean	2.5	2.6	3.2	3.0	2.1		2.3	2.3	2.4	2.2	2.2	2.6	2.5	2.3	2.2	2.4	2.5	2.7
	sd	0.29	0.19	0.23	0.65	0.25		0.24	0.42	0.29	0.19	0.23	0.21	0.21	0.42	0.21	0.15	0.17	0.21
	min max	2.2 2.7	2.5 2.9	3.0 3.5	2.0 3.7	1.7 2.4		1.9 2.7	1.6 3.0	2.0 2.8	2.0 2.5	1.9 2.5	2.4 2.8	2.3 2.6	2.0 2.6	2.0 2.4	2.3 2.6	2.3 2.8	2.5 2.8
PESW	n	3	4	5	7	6	0	13	9	5	8	9	3	2	2	3	3	6	2
	mean	3.5	3.4	3.9	3.9	2.7		3.0	3.5	3.2	3.4	2.9	2.9	2.6	2.5	2.9	3.1	3.3	3.2
	sd	0.25	0.35	0.26	0.40	0.15		0.24	0.32	0.22	0.47	0.35	0.17	0.00	0.07	0.06	0.26	0.30	0.35
	min max	3.3 3.8	3.2 3.9	3.5 4.2	3.3 4.3	2.5 2.9		2.6 3.3	3.2 4.1	3.0 3.5	2.6 4.0	2.4 3.5	2.8 3.1	2.6 2.6	2.5 2.6	2.9 3.0	2.8 3.3	2.9 3.7	3.0 3.5
PESL	n	3	4	5	7	6	0	13	9	5	8	9	3	2	2	3	3	6	2
	mean	16.5	16.5	19.0	17.8	13.9		14.9	14.8	15.9	15.3	14.6	13.5	13.8	14.6	15.3	15.6	17.1	16.2
	sd	0.38	0.43	1.31	0.47	0.80		0.93	1.09	0.81	0.71	0.44	1.12	1.20	0.99	0.70	1.39	0.90	0.64
	min max	16.1 16.8	16.0 17.0	17.5 20.9	17.0 18.4	13.0 15.2		13.8 17.2	13.3 16.8	14.7 16.7	13.7 16.1	14.1 15.5	12.5 14.7	12.9 14.6	13.9 15.3	14.6 16.0	14.4 17.1	16.1 18.1	15.7 16.6
EARL	N	3	3	5	7	5	0	13	9	5	8	9	3	2	2	3	3	6	2
	mean	11.2	11.7	12.1	11.4	10.6		10.2	10.6	12.1	11.7	11.0	10.2	11.3	11.3	10.6	10.8	12.3	12.6
	sd	0.53	0.72	0.77	0.85	0.50		1.15	1.01	1.31	0.80	1.08	0.59	0.64	0.35	0.57	0.98	0.72	0.00
	min max	10.8 11.8	10.9 12.2	10.9 13.0	10.3 12.7	9.8 11.0		8.3 11.9	9.3 12.3	10.6 13.9	10.9 13.4	9.6 13.2	9.8 10.9	10.8 11.7	11.0 11.5	10.2 11.0	10.2 11.9	11.5 13.1	12.6 12.6

New records for Hemiptera species in Western Australia

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Abstract – Four genera and nine species of Hemiptera from other states and territories have recently been recorded in Western Australia for the first time. Material has originated mainly from Jarrahdale, approximately 50 kms SE of Perth. Newly recorded species include one species of Cercopidae, five of Cicadellidae, one of Ricaniidae, one of Scutelleridae and one of Pentatomidae.

INTRODUCTION

The Hemiptera of Western Australia are poorly known compared to Eastern Australia, possibly owing to the State's isolation from the main population centres of Australia, and the lack of local hemipteran taxonomists in the state. Even species representing potential threat to agriculture and/or forestry appear to have been overlooked, with the exception of introduced aphids. A few authors have attempted to catalogue Hemiptera within certain regions of WA (Abbott 1995; Cassis and Gross 1995, 2002; Heterick *et al.* 2001), although such catalogues rely on rather infrequent ground surveys of taxa. The first author has been investigating the understorey-associated Hemiptera of the northern jarrah (*Eucalyptus marginata* Sm.) forest at Jarrahdale, WA. New records of Hemiptera for WA, revealed by this study, are presented here.

METHODS

Specimens were collected by beating and suction sampling (see Smith 1999) at Jarrahdale, approximately 50 km SE of Perth in WA, at 32°14'S 116°05'E. Understorey plant species from the families Zamiaceae (*Macrozamia*), Proteaceae (*Adenanthos* and *Hakea*), Fabaceae (*Bossiaea* and *Mirbelia*), Mimosaceae (*Acacia*), Dasypogonaceae (*Lomandra*), Myrtaceae (*Melaleuca*), Rhamnaceae (*Trymalium*), Epacridaceae (*Leucopogon*) and Poaceae (*Ehrharta*) were sampled. The two sampling methods were used on numerous understorey plant species of the jarrah forest, over a period of 20 months, resulting in excess of 26 000 hemipteran specimens, representing at least 380 species. At least nine of these represented records that were new to WA. Other collections examined for records of these newly recorded species, were those of the Western Australian Museum, Department of Agriculture WA, Department of Environmental Biology at

Curtin University, and A. Postle's Argyle Diamond Mines specimens (lodged in the WA Museum and Department of Environmental Biology). The methods utilised by Postle (1984) were light traps, sweeps, malaise traps and pitfall traps. Voucher specimens of adults collected by the first author have been lodged with the Western Australian Museum and, in some cases, the Department of Agriculture, WA.

Abbreviations used: ASCU, Agricultural Scientific Collections Unit, NSW Agriculture, Orange; NSW, New South Wales; Qld, Queensland; Vic, Victoria; SA, South Australia; NT, Northern Territory; Tas, Tasmania; WA, Western Australia; WAM, Western Australian Museum, Perth; WADA, Entomological collection, Department of Agriculture Western Australia, Perth.

NEW RECORDS

Suborder Auchenorrhyncha

Family Cercopidae

Petyllis deprivata (Walker, 1858)

Material examined: 4♂, Jarrahdale jarrah forest (32°14'S 116°05'E), November 2000, M. Moir, on FABACEAE: *Bossiaea aquifolium* (Benth.) (suction sampling); DASYPOGONACEAE: *Lomandra sonderi* (Muell.) (suction sampling); ZAMIACEAE: *Macrozamia riedlei* (Gaudich.) (suction sampling); PROTEACEAE: *Adenanthos barbiger* (Lindl.) (suction sampling) (WAM); 1♀, Dog Pool, Shannon National Park (34°46'S 116°22'E), 22–25 March 1993, M.S. Harvey and J.M. Waldock (WAM 33561); 1 (genitalia missing), Glen Forest, Perth, Darling Range, November 1975, S.M. Postmus (WAM 33560); 1 (genitalia missing), Mt Clarence, Albany, 10 January 1941, P.N.F. (WADA 16200); 1♂, Denmark, 8 December 1972, P.N. Forte (WADA

16201); 1♂ 2♀, Mandurah, 27.xi.1969, K.T. Richards (WADA 16196, 16197 and 16198); 1♀, Banister, 15 January 1971, K.T. Richards (WADA 16202); 1♀, Northam, 18 November 1982, K.T. Richards (WADA 16203); 1♀, Yanchep, March 1973, S.J. Curry (WADA 16202), light trap.

Note: This is the first record of this genus in WA. *Petyllis deprivata* has been recorded from Qld, NSW and Vic by Fletcher and Larivière (2001), and the material examined demonstrates that it is also distributed between Perth and Albany in WA. Plant species on which it has been collected in WA indicate that this cercopid may have a wide host range, although it was collected mainly in jarrah forest. These host plants possibly include members of the Fabaceae, Zamiaceae, Proteaceae and Dasypogonaceae (*Lomandra*). The specimens collected to date indicate that *P. deprivata* is active during late spring to autumn in WA.

Family Ricaniidae

Epithalamium aziola (Kirkaldy, 1906)

Material examined: 1♀, Jarrahdale rehabilitated mine pit (32°14'S 116°05'E), April 2000, M. Moir, suction sampling; 13♀ 4♂, Jarrahdale rehabilitated mine pit and surrounding jarrah forest (32°14'S 116°05'E), ii.2001, M. Moir, on FABACEAE: *B. aquifolium* (suction sampling), *Mirbelia dilatata* (R.Br.) (suction sampling and beating); PROTEACEAE: *Hakea lissocarpa* (R.Br.) (suction sampling); MIMOSACEAE: *Acacia pulchella* (R.Br.) (beating), *Acacia drummondii* (Lindl.) (beating), *Acacia trigonophylla* (Meisn.) (beating) (7♀ 2♂ in each of WAM and WADA).

Note: This material represents the first record of the genus from WA. A small and attractive species of ricaniid planthopper, this species was described in a monotypic genus by Kirkaldy (1906) from Sydney, but few further records exist for the species. Fletcher and Larivière (2001) provide an illustration of the species based on specimens collected in 1977 by M.J. Fletcher at Mount White, North of Sydney. There are also two specimens in ASCU collected at Tahmoor, NSW, by C.E. Chadwick in 1966. In the northern jarrah forest of WA, the species appears to be active during late summer to early autumn. It is likely that *M. dilatata* and certain *Acacia* species are hosts.

Family Cicadellidae

Subfamily Ulopinae

Tribe Ulopiini

Austrolopa sp. (Evans, 1937)

Material examined: 1♂ 22♀, Jarrahdale rehabilitated mine pit and surrounding jarrah forest

(32°14'S 116°05'E), May–August 2001, M. Moir, on FABACEAE: *B. aquifolium* (suction sampling and beating), *M. dilatata* (suction sampling and beating); MYRTACEAE: *Melaleuca* sp. (beating); PROTEACEAE: *H. lissocarpa* (beating); RHAMNACEAE: *Trymalium ledifolium* (Fenzl, 1837) (beating) (1♂ 11♀ in WADA, 11♀ in WAM); 1♂, Beedelup National Park, karri forest, Pemberton, ii.2003, M. Moir and K.E.C. Brennan, on *B. aquifolium* (beating) (WAM).

Note: This material represents the first record of the genus *Austrolopa* from WA. *Austrolopa* currently includes two described species, *A. brunensis* Evans (1937) and *A. victoriensis* Evans (1939). The former is widespread in eastern Australia and has also been recorded in SA and Tas (Day and Fletcher 1994). The latter is known only from the female type specimen, collected from Warburton, Vic. The two species were differentiated by Evans (1966) by the length of the vertex, but this character is somewhat variable and further specimens of *A. victoriensis* from SE Australia, particularly males, are needed to support the recognition of *A. victoriensis* as a valid species. *Austrolopa brunensis* is known in several colour forms, and in both macropterous and brachypterous forms. No specimens collected from WA display brachyptery. *Austrolopa* adults and nymphs were common in the southwest on *B. aquifolium* and *M. dilatata*, although adults were occasionally collected on other plant species. Western Australian host plant records conform to eastern state hosts of *Bossiaea* and other Fabaceae species for *A. brunensis* (Day and Fletcher 1994; Fletcher and Larivière 2001). It appears that the *Austrolopa* species recorded in WA is distributed widely on *B. aquifolium*, as collections on this host plant were recorded at sites over 200km apart (Jarrahdale to Pemberton). However, a study of the genus *Austrolopa* from all parts of Australia is required to determine whether more than one species can be recognised, or whether the genus contains only a highly variable *A. brunensis*.

Subfamily Typhlocybinae

Tribe Erythroneurini

Zygina zealandica (Myers, 1923)

Material examined: 14♂ 15♀, Jarrahdale rehabilitated mine pit and surrounding jarrah forest (32°14'S 116°05'E), April 2000 – November 2001, M. Moir, on FABACEAE: *B. aquifolium* (chemical knockdown), *M. dilatata* (suction sampling); PROTEACEAE: *H. lissocarpa* (suction sampling); MIMOSACEAE: *A. pulchella* (suction sampling); RHAMNACEAE: *T. ledifolium* (beating) (7♂ 8♀ in WAM, 7♂ 7♀ in WADA); 7♂ 4♀, Como, Perth, October 2002, M. Moir, POACEAE: *Ehrharta longiflora* (Sm.) (hand collection) (WAM).

Note: This species is common and widespread in eastern Australia and New Zealand on a very wide range of host plants (Knight 1976). Its presence in WA on many plant species is not surprising and it is presumably also present in SA, although the species has not yet been confirmed in that State.

Subfamily Deltocephalinae

Tribe Macrostelini

Balclutha viridinervis (Matsumura, 1914)

Material examined: 1♀, Como, Perth, January 2002, M. Moir, by fluorescent light (WAM).

Note: This species is distributed in SE Asia and the western Pacific from India to New Zealand. In Australia it has been recorded in NT, NSW, Qld (Knight 1983; Fletcher and Larivière 2001). This record from WA needs to be confirmed by examination of the genitalia of a male. The record may represent a recent introduction to WA, as the species has a wide distribution, and the single specimen examined was collected from a suburban garden of Perth.

Balclutha incisa (Matsumura, 1902)

Material examined: 1♂, Jarrahdale rehabilitated mine pit (32°14'S 116°05'E), April 2000, M. Moir, on MIMOSACEAE: *A. pulchella* (chemical knockdown) (WAM); 1♂, Lennard River crossing Gibb River road, Kimberley (17°23'S 124°44'E), 14–28 July 1988, T. Houston, Malaise trap (WAM 33562).

Note: *B. incisa* is one of the most common species of grass-feeding leafhoppers in Australia but has not previously been formally recorded from WA (Knight 1987; Fletcher and Larivière 2001). Given the species' wide host range and large distribution, the paucity of specimens captured at Jarrahdale suggests that *B. incisa* could be a recent introduction.

Tribe Athysanini

Limotettix incertus (Evans, 1966)

Material examined: 1♀, Jarrahdale rehabilitated mine pit (32°14'S 116°05'E), November 2000, M. Moir, suction sampling (WADA); 1♀, Argyle Diamond Mines, Kununurra, December 1983, A. Postle, light trap (WAM); 4♀, Mussel Pool, 7 km NW of Midland (32°14'S 116°05'E), 24 November 1975, S.M. Postmus (WAM 33563–33566); 1♀, Marandoo camp, Karijini National Park, Pilbara (22°38'S 118°06'E), 5–29 May 1980, T.F. Houston (WAM 33567).

Note: A common species in eastern Australia and an adventive in New Zealand (Evans 1966). The wide distribution within WA indicates a wide natural range, rather than this being a more recent introduction. Host plant information is not available for this species as the method utilised (light traps) does not allow such records, and few specimens have been captured and identified to date.

Suborder Heteroptera

Family Scutelleridae

Subfamily Odontotarsinae

Morbora australis (Distant, 1899)

Material examined: 1♀, Jarrahdale rehabilitated mine pit (32°14'S 116°05'E), November 2001, M. Moir, on MIMOSACEAE: *A. pulchella* (beating) (WADA); 1♀, Mundrabilla Station (via Eucla), 7 January 1990, R. Patterson, under *Eucalyptus* sp. bark (WAM 33559).

Note: This is the first record of the genus in WA for this unusual Scutelleridae, which is distinctive due to its dull brown coloration (unlike other species in this family) and spines on the pronotum. Although the genus and species are poorly known, the species has been recorded from most states and territories of Australia (Gross 1975).

Family Pentatomidae

Subfamily Pentatominae

Gilippsus hostilis (Hagland, 1868)

Material examined: 2♀, Jarrahdale rehabilitated mine pit and surrounding jarrah forest (32°14'S 116°05'E), November 2000 and November 2001, M. Moir, on EPACRIDACEAE: *Leucopogon nutans* (Pritz) (beating) (1♀ in each of WAM and WADA).

Note: This species has been recorded previously from NSW and Vic (Gross 1976). It may be active during late spring, as both females were collected during November.

DISCUSSION

The most common of the newly recorded Hemiptera were *Z. zealandica*, *Austrolopa* sp. and *E. aziola* (506, 21 and 18 specimens collected at Jarrahdale, respectively). *Zygina zealandica* and *Austrolopa* sp. were found easily and it is probable that these species have always been present in the southwest. It is possible that they have gone unnoticed until the present, possibly due to a lack of hemipteran surveys.

Single specimens of *M. australis*, *B. viridinervis*, *B.*

incisa and *L. incertus* were obtained at Jarrahdale. Other species that were represented by fewer than five specimens at Jarrahdale were *G. hostilis* and *P. deprivata*. Considering the intensity of the collection methods for the understorey, and the total number of hemipterans collected, populations of the above-mentioned species were thought to be in low abundance at Jarrahdale. Whether these species are recent introductions to WA is unknown, although the small populations would have inhibited the chance of previous discovery. If species are present most of the year, either as eggs, nymphs or overwintering in leaf litter, further difficulty could be expected in collecting and recording them. One particular cicadellid, *L. incertus*, has a large distribution over the State, as specimens were collected over 2200km apart (Jarrahdale, Swan Coastal Plain, Karijini National Park and Kununurra). Although sampling was conducted intensively at Jarrahdale and Kununurra, only single specimens were obtained. The singletons from most locations suggest either that the species is at the limit of its range, populations occur in extremely low abundance, or that the host plants were not targeted in the sampling effort (for further discussion on singletons see Novotny and Basset 2000).

Herbivorous Hemiptera are thought to have close relationships with the plant species upon which they feed (New 1988; Carver *et al.* 1991). Future surveys, therefore, should incorporate host plant data to uncover more information about this interesting group. Further collections of Hemiptera will, undoubtedly, reveal more described species in WA. In addition to new records such as these, many undescribed species and genera are expected with an increase in surveys. For example, the Jarrahdale Hemiptera study has revealed in excess of 250 species that are yet to be described.

ACKNOWLEDGEMENTS

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First valid record of *Astacilla* Cordiner, 1793 in Australia, with description of a new species (Crustacea: Isopoda: Arcturidae)

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Abstract – A new species of arcturid isopod, *Astacilla lewtonae*, is described from Western Australia. Although other Australian species have been attributed previously to this genus, this is the first record for the genus as currently diagnosed.

INTRODUCTION

The Arcturidae Dana, 1849 are a specialised group of marine isopods, which use the anterior four pairs of pereopods as a setose filtering complex extending from a cylindrical body usually elevated above the substrate. The family belongs to the isopod suborder Valvifera, which has recently been restricted by Poore (2001) who removed many genera traditionally placed in it to other families, Antarcturidae Poore, 2001 in particular.

The first description of an Australian arcturid isopod was of *Arcturus brevicornis* Haswell, 1881 from New South Wales. The types of this species are lost but it is probably a species of *Neastacilla*. Further species of *Arcturus* were described from New South Wales by Whitelegge (1904), *Arcturus alcornis*, *A. dentatus*, *A. nodosus*, *A. serratus*, *A. simplicissimus*, the types of all of which are also lost. All probably belong in the Antarcturidae.

The first review of Australian arcturid taxa was that of Hale (1924), who examined many specimens and established the endemic genus *Parastacilla* for two very distinctive species. He also described two other species and placed them in *Neastacilla* Tattersall (*Neastacilla algensis* and *Neastacilla deducta*). In a further, more comprehensive, review Hale (1946) described five arcturid species from the Southern Hemisphere and placed them all in *Astacilla* (*Astacilla attenuata*, *A. macilenta*, *A. sheardi* and *A. vicaria* from Australia and *A. fusiformis* from New Zealand) arguing that the genus *Neastacilla* Tattersall was poorly differentiated from *Astacilla* and should not be recognised. Hale (1946) re-examined his two previously described Australian species, *Neastacilla algensis* Hale, 1924 and *Neastacilla deducta* Hale, 1924, moving both to *Astacilla*, and included *Astacilla marionensis* Beddard, 1886 and *Astacilla kerguelensis* Vanhöffen, 1914 from the Southern Ocean in his discussion.

Guiler (1949) was also reluctant to confirm the genus *Neastacilla* and described five new Tasmanian species of *Astacilla* (*Astacilla monoseta*, *A. inaequispinosa*, *A. unicornis*, *A. derwenti*, and *A. oculata*). Of these, only *A. monoseta* and *A. inaequispinosa* are currently valid species (Poore *et al.*, 2002).

All southern Pacific species of *Astacilla* were removed to *Neastacilla* by Kussakin (1972) who published a new diagnosis of *Neastacilla*. A thorough review of 18 Australian species of *Neastacilla* (Lew Ton, 1980) concurred with Kussakin's conclusions, finding that *Neastacilla* was a valid Pacific genus clearly separated from *Astacilla*, which had no known representatives in Australia. So, until now the family has been represented in Australia by *Amesopous* Stebbing, 1905, *Neastacilla* Tattersall, 1921, and *Parastacilla* Hale, 1924, only the last being endemic (King, 2000; Poore *et al.*, 2002).

Although *Astacilla* is almost certainly paraphyletic (King, 2001), a useful diagnosis can be written. *Astacilla* currently comprises 32 species distributed in the northern and central North Atlantic, Mediterranean, northern North Pacific, southern Africa, and in India (Table 1). The new species described here extends the range of the genus to the eastern Indian Ocean and is the first record from Australia.

Material is deposited in the Western Australian Museum, Perth (WAM) and Museum Victoria, Melbourne (NMV).

SYSTEMATICS

Astacilla Cordiner, 1793

Astacilla Cordiner, 1793. –Sars, 1897: 87. –Monod, 1970: 1127–1142. –Kensley, 1983: 163–164.

Table 1 The species of *Astacilla* and their distributions.

Species	Distribution
<i>A. amblyura</i> Stebbing, 1905	Southern India (Pillai, 1963).
<i>A. arietina</i> Sars, 1882	Norway, North Atlantic (Sars, 1897; Kussakin, 1982).
<i>A. axeli</i> Castelló, 1992	Western Mediterranean (Castelló, 1997).
<i>A. bispinata</i> (Menzies & Kruczynski, 1983)	Gulf of Mexico.
<i>A. bocagei</i> Nobre, 1903	Portugal.
<i>A. bonnierii</i> Stephensen, 1915	Straits of Gibraltar; Mediterranean.
<i>A. caeca</i> Benedict, 1898	North Atlantic (Richardson, 1905; Schultz, 1969; Kussakin, 1982).
<i>A. cinguicula</i> Castelló & Carballo, 2000	Western Mediterranean.
<i>A. corniger</i> (Stebbing, 1873)	South Africa (Barnard, 1914, 1920; Kensley, 1978, 1984).
Junior synonyms include: <i>Antarcturus ornatus</i> , Tattersall, 1913; <i>Astacilla setosa</i> Vanhöffen, 1914; <i>Arcturopsis hirsutus</i> Barnard, 1914; <i>Arcturopsis hirsutus</i> subglaber Barnard, 1914.	
<i>A. cymodocea</i> Menzies & Glynn, 1968	Gulf of Mexico, Caribbean (Kensley & Schotte, 1989).
<i>A. depressa</i> Castelló & Poore, 1998	western Mediterranean.
<i>A. deshayesii</i> Lucas, 1849	Europe
<i>A. eminentia</i> Kensley, 1984	South Africa.
<i>A. gibbosa</i> Pillai, 1954	India (Pillai, 1963).
<i>A. glabrus</i> (Benedict, 1898)	Bering Sea, north western Pacific Ocean (Richardson, 1899, 1905, 1909; Birstein, 1963; Schultz, 1969; Kussakin, 1982).
<i>A. gorgonophila</i> Monod, 1925	north Africa; Mediterranean.
<i>A. granulata</i> (Sars, 1877)	eastern USA, United Kingdom, Norwegian Sea (Harger, 1880; Benedict, 1898; Richardson, 1905; Schultz, 1969; Kussakin, 1982).
	Junior synonym: <i>Astacilla americana</i> Harger, 1878.
	United Kingdom, Scandinavia (Kussakin, 1982). Junior synonym: <i>Arcturus affinis</i> Sars, 1869.
<i>A. intermedia</i> (Goodsir, 1841)	western Mediterranean.
<i>A. laevis</i> Castelló & Poore, 1998	Texas; Georgia (Schultz, 1969; Clark & Robertson, 1982).
<i>A. lauffi</i> Menzies & Frankberg, 1966	Venezuela (Kensley & Schotte, 1989).
<i>A. lasallae</i> Paul & Menzies, 1971	United Kingdom; Scandinavia (Sars, 1897; Stephensen, 1948; Gruner, 1965; Naylor, 1972; Kussakin, 1982).
<i>A. longicornis</i> (Sowerby, 1805) Junior synonyms include: <i>Leacia lacertosa</i> Johnston, 1825; <i>Leachia gracilis</i> Goodsir, 1841; <i>Arcturus deshayesii</i> Lucas, 1849; <i>Arcturus linearis</i> Stebbing, 1878.	
<i>A. longispina</i> (Kensley, 1978)	South Africa (Kensley, 1978; Kensley, 1984).
<i>A. marna</i> Kensley & Schotte, 1994	Dominica.
<i>A. mediterranea</i> Koehler, 1911	Mediterranean (Barnard, 1920; Kensley, 1984; Kensley, 1978; Kensley, 1984).
<i>A. monodi</i> Tattersall, 1925	Mauritania.
<i>A. paucisetosa</i> Castelló & Caballo, 2000	Western Mediterranean.
<i>A. pusilla</i> (Sars, 1873)	Scandinavia (Sars, 1897; Kussakin, 1982).
<i>A. serrata</i> Nunomura, 1998	Japan.
<i>A. spinata</i> (Menzies & Kruczynski, 1983) Junior synonym: <i>A. regina</i> Kensley, 1984; (Kensley & Schotte, 1989).	Belize, Barbados, St Lucia.
<i>A. tayronae</i> Müller, 1993	Columbia
<i>A. tranquilla</i> (Kensley, 1975)	South Africa (Kensley, 1978, 1984).

Species transferred to other genera:

<i>A. anophthalmus</i> Birstein, 1963	<i>Arcturus</i> .
<i>A. attentuata</i> Hale, 1946	<i>Neastacilla</i> .
<i>A. bacillus</i> Barnard, 1920	<i>Neastacilla</i> .
<i>A. californica</i> Boone, 1918	<i>Neastacilla</i> .
<i>A. dilatata</i> Richardson, 1909	preoccupied, replacement name: <i>Neastacilla richardsonae</i> .
<i>A. dilatata</i> Sars, 1882	type species of <i>Arcturella</i> .
<i>A. diomedae</i> Benedict, 1898	<i>Neastacilla</i> .
<i>A. estadoensis</i> Schultz, 1981	<i>Neastacilla</i> .
<i>A. falclandica</i> Ohlin, 1901	type species of <i>Neastacilla</i> .
<i>A. fusiformis</i> Hale, 1946	<i>Neastacilla</i> .

Table 1 (cont.)

Species	Distribution
<i>A. giardi</i> Bonnier, 1896	<i>Arcturopsis</i> .
<i>A. inaequispinosa</i> Guiler, 1949	<i>Neastacilla</i> .
<i>A. kerguelensis</i> Vanhoeffen, 1914	<i>Neastacilla</i> .
<i>A. levis</i> Thomson & Anderton, 1921	<i>Neastacilla</i> .
<i>A. macilenta</i> Hale, 1946	<i>Neastacilla</i> .
<i>A. magellanica</i> Ohlin, 1901	<i>Neastacilla</i> .
<i>A. marionensis</i> Beddard, 1886	<i>Neastacilla</i> .
<i>A. monoseta</i> Guiler, 1949	<i>Neastacilla</i> .
<i>A. polita</i> Gurjanova, 1936	<i>Neastacilla</i> .
<i>A. setosa</i> Vanhoeffen, 1914	junior synonym of <i>Astacilla corniger</i> .
<i>A. sheardi</i> Hale, 1946	<i>Neastacilla</i> .
<i>A. vicaria</i> Hale, 1946	<i>Neastacilla</i> .
<i>Leachia gracilis</i> Goodsir, 1841	junior synonym of <i>Astacilla longicornis</i> .
<i>L. granulata</i> Sars, 1877	<i>Astacilla</i> .
<i>L. intermedia</i> Goodsir, 1841	<i>Astacilla</i> .
<i>L. nodosa</i> Dana, 1849	<i>Arcturella</i> .
<i>Leacia lacertosa</i> Johnston, 1825	junior synonym of <i>Astacilla intermedia</i> .

Type species

Oniscus longicornis Sowerby, 1805, subsequent designation by Fowler, 1912 (ICZN, 1986: Opinion 1369).

Diagnosis

Body strongly geniculate between pereonites 4 and 5, cylindrical, with no dorsal ridge. Antenna 2 slender, 2 or 3 flagellar articles, flagellum ending with claw. Maxillipedal palp with all segments free, palp article 3 similar width as article 2. Pereonite 4 elongate, male and female of similar length.

Pereopod 1 setose, with unguis (rarely without). Pereopods 2–4 present and functional as setose appendages, dactylus absent. Pereopods 2–4 cylindrical, held close to the mouthparts, able to extend past the mouthparts, setae in rows, setae as long as segment, flexion between the carpus and the propodus present. Pereopods 5–7 with 2 ungues, secondary unguis robust.

Penial plate narrow, apex simple. Male pleopod 1 with lateral notch, with 3 lateral setae, lateral setae of similar length. Male pleopod 2 with appendix masculina tapered, without ridge, distally not widened, straight, elongated.

Uropodal exopod present, 3 setae on inner ramus.

Female functional brood pouch majority made up of pereonite 4 (or 3 and 4). Oostegite 5 absent.

Remarks

The systematics of the genus *Astacilla* is currently unresolved, given the similarities of many species to those in the genera *Arcturella* and *Neastacilla*. In the past *Astacilla* has been successively defined by

an elongate fifth pereonite (Bate & Westwood, 1868), pereopod 1 with a claw, one pair of oostegites (Sars, 1897), and the loss of dactyls on pereopods 2 to 4 (Kussakin, 1972). Examination of several species of *Astacilla* has shown that these characters are variable and in the case of the number of oostegites, incorrect. The lack of known synapomorphic character states for many arcturid genera combined with the reluctance of many authors to examine the higher systematics of the genera has lead to much confusion within arcturid taxonomy and much debate (Nordenstam, 1933; Monod, 1970; Kussakin, 1972; Schultz, 1981; Menzies & Kruczynski, 1983; Wägele, 1989; Brandt, 1991).

Astacilla lewtonae sp. nov.

Figures 1–4

Material examined

Holotype

Male, 7.3 mm, Western Australia, between Dampier and Port Hedland, 19°03.00'S; 119°00.00'E, 80 m, WHOI epibenthic sled, CSIRO division of Fisheries, 11 Dec 1982 (WAM C 32344).

Paratypes

Female, 6.0 mm, Western Australia, between Dampier and Port Hedland, 19°37.00'S; 118°53.00'E, 30 m, WHOI epibenthic sled, CSIRO division of Fisheries, 3 Jun 1983 (WAM C 32345). 2 females; 7.0–7.5 mm, 19°28.40'S; 118°55.10'E, 38 m, WHOI epibenthic sled, CSIRO division of Fisheries, 25 Oct 1983 (WAM C 32346). Immature male, 5 mm,

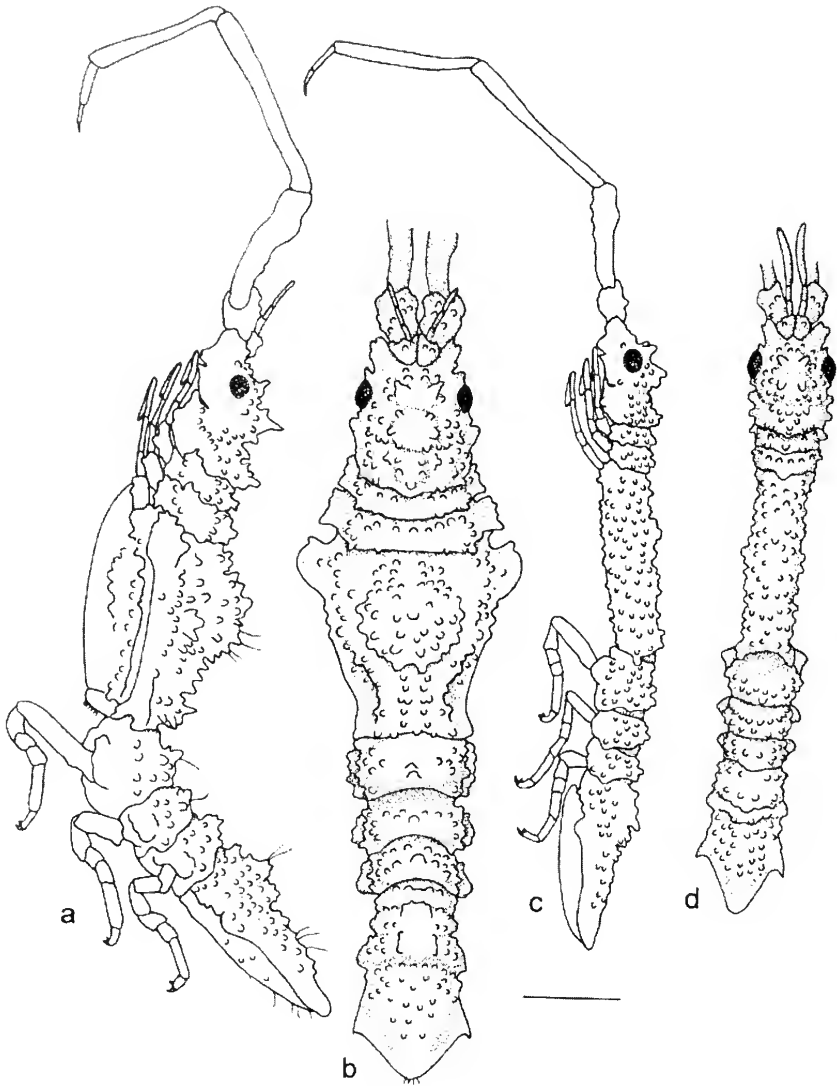


Figure 1 *Astacilla lewtonae* n.sp., female holotype (NMV J16900): a, lateral view; b, dorsal view. Male (NMV J16904): c, lateral view; d, dorsal view. Scale = 1.0 mm.

19°29.90'S; 118°52.00'E, 37 m, WHOI epibenthic sled, CSIRO division of Fisheries, 24 Oct 1983 (NMV J16651). Manca 2, 3 mm, 19°50.00'S; 118°57.90'E, 84 m, WHOI epibenthic sled, CSIRO division of Fisheries, 29 Aug 1983 (NMV J16667). 3 females; 6.5–7.0 mm, 19°29.60'S; 118°51.70'E, 40 m, WHOI epibenthic sled, CSIRO division of Fisheries, 25 Oct 1983 (NMV J16648).

Other material examined

Northern Territory, North West end, Bommies, McCluer Island, 11°02.00'S; 132°58.00'E, 8 m, SCUBA, in sponges, Lowry, J.K., 16 Oct 1982 (NMV

J16582). 11°02.00'S; 132°58.00'E, 8 m, SCUBA, in hydroids, Lowry, J.K., 16 Oct 1982 (NMV J16935).

South Australia, Spencer Gulf, Douglas Bank, 32°47.18'S; 137°50.00'E, 15 m, South Australia Fisheries, Aug 1986 (NMV J16917).

Description

Female

Body geniculate and cylindrical. Anterolateral margins of head sub-truncate with medial indentation, a small rostral point evident. Fusion of head and pereonite 1 indicated by dorsolateral groove incised laterally. Head heavily tuberculate,

with 2 tuberculate dorsal elevations central and posterior to eyes, anterior tubercle with 2 apices. Pereonite 2 wider than pereonite 1, tuberculate with angular lateral margins extended. Pereonite 3 wider than pereonite 2, tuberculate with angular lateral margins extended. Pereonite 4 about 6 times longer than pereonite 3; dorsally wider than pereonite 3, tuberculate, angular lateral margins extended, with small posterior lateral extensions. Pereonites 5 to 7 progressively shorter posteriorly; heavily tuberculate, with lateral extensions. Pleon with evidence of three fused pleonites plus pleotelson; total length longer than combined lengths of pereonites 5 to 7, with small anterior lateral wings, posterior angular lateral wings and rounded apex.

Eyes round, dorsolateral. Antenna 1 reaching past distal edge of second peduncular article of antenna 2; flagellum slender with aesthetascs attached distally. Antenna 2 slender, more than half as long as body; flagellum of 2 articles plus claw, lower margin without scales.

Maxilla 1 inner lobe with 3 terminal setae; outer lobe with 10 robust setae. Maxilla 2 inner lobe with 15 plumose setae; middle lobe with 4 setae; outer lobe with 3 setae. Maxillipedal endite with 10 mesial setae; palp article 2 and 3 with mesial setal rows; article 4 with mesial and lateral setal rows; article 5 with distal setae.

Pereopod 1 propodus smaller than carpus; dactylus about twice as long as wide, bearing unguis, which is longer than dactylus. Pereopods 2–4 merus to propodus with paired rows of long setae; dactylus absent; flexion between carpus and propodus present.

Pereopods 5 to 7 progressively shorter; dactylus denticulate, unguis present with secondary unguis 2/3 length of primary unguis.

Uropod exopod not reaching mid point of endopod, with 2 setae of subequal length.

Oostegites present on pereopods 1 to 4; oostegite 4 thickened, with transverse suture delimiting posterior lobe.

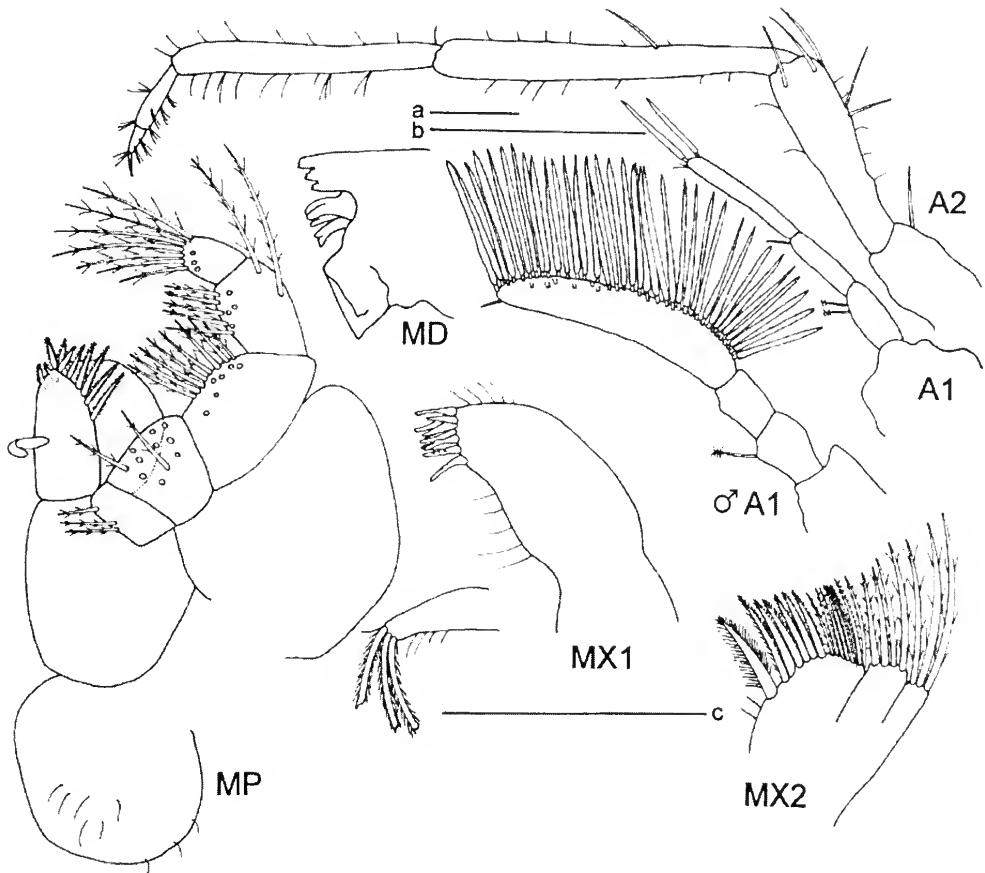


Figure 2 *Astacilla lewtonae* n.sp., female holotype (NMV J16900): left maxilliped; left maxillae 1 and 2; left mandible; antennae 1 and 2. Scales: a (A2) = 0.5 mm; b (A1, ♂ A1) = 0.5 mm; c (MP, MX1, MX2, MD) = 0.5 mm.

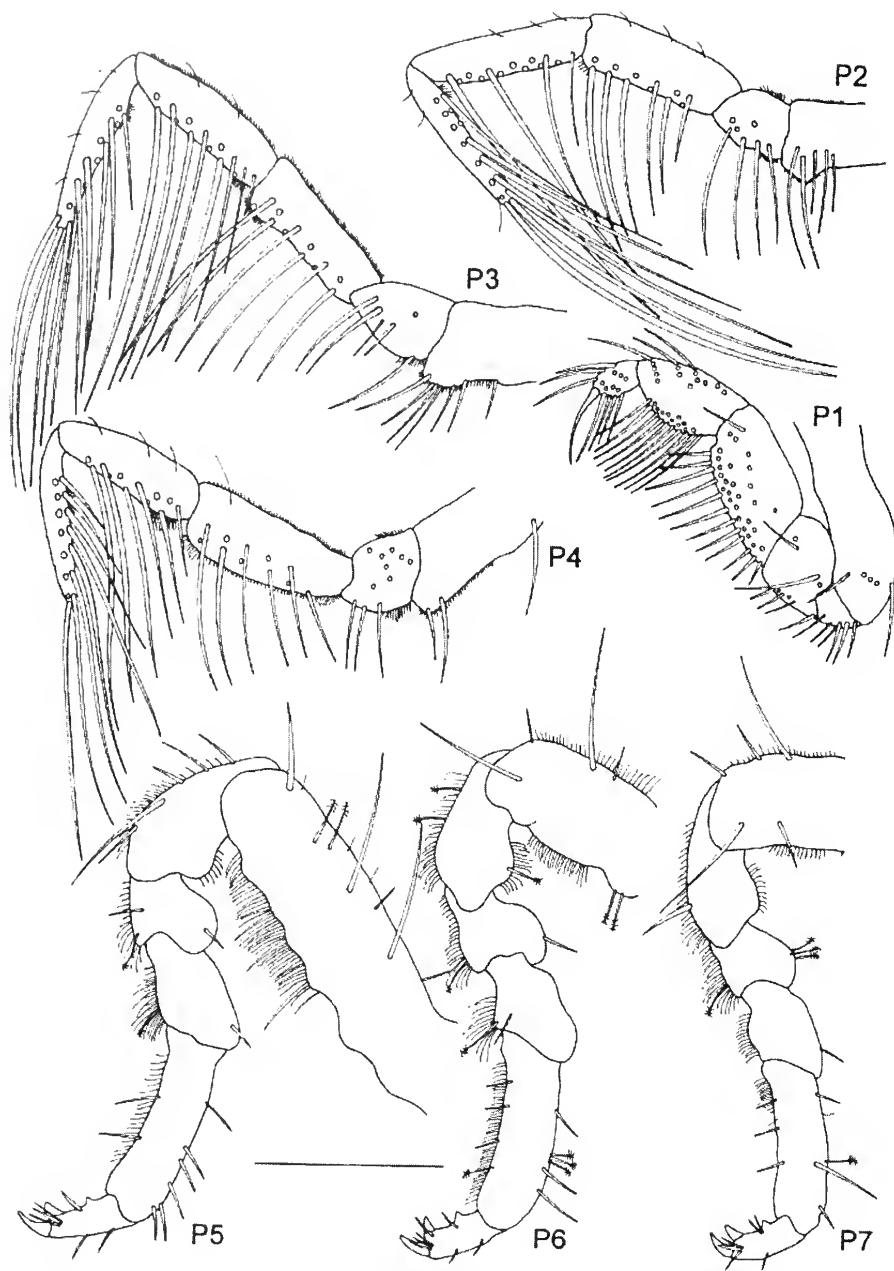


Figure 3 *Astacilla lewtonae* n.sp., female holotype (NMV J16900): pereopods 1 to 7. Scale = 0.5 mm.

Male

Body geniculate and cylindrical. Anterolateral lobes of head rounded with tuberculations, small rostral point evident. Head and pereonite 1 fused and with similar tuberculate ornamentation to female. Pereonite 2 and 3 tuberculate; lateral margins not greatly extended. Pereonite 4 around 8 times length of pereonite 3, tuberculate, lateral

margins not extended. Pereonites 5 to 7 tuberculate, anterolateral margins extended. Pleon length greater than combined lengths of pereonites 5 to 7, evidence of 3 fused pleonites plus pleotelson, with small anterior lateral wings, angular posterior lateral wings and rounded apex.

Eyes round and dorsolateral. Antenna 1 extending past distal edge of second peduncular

article of antenna 2; flagellum uniarticulate and with aesthetascs attached distally and laterally along the entire length. Antenna 2 as for female.

Mouthparts as for female.

Pereopods as for female.

Pleopod 1 exopod with lateral notch and 3 plumose setae of similar lengths on posterior face. Pleopod 2 with appendix masculina straight and extending twice the length of the endopod, tapering to two filaments. Penial plate straight and simple.

Distribution

Australia: Western Australia, Northern Territory, South Australia; 8 to 84 metres.

Remarks

Although morphologically similar to Australian *Neastacilla* species, the possession of a long, straight appendix masculina is the primary reason why this species belongs in *Astacilla*. Other characteristics that support the placement of this species within *Astacilla* are the possession of flexion between the carpus and propodus and the complete lack of dactyli on pereopods 2 to 4, the presence of a dactylus on pereopod 1 and the shape of the female, which is widened and not especially elongate at pereonite 4. The dorsal and lateral sculpture of the body of this species makes it unique among the *Astacilla* species.

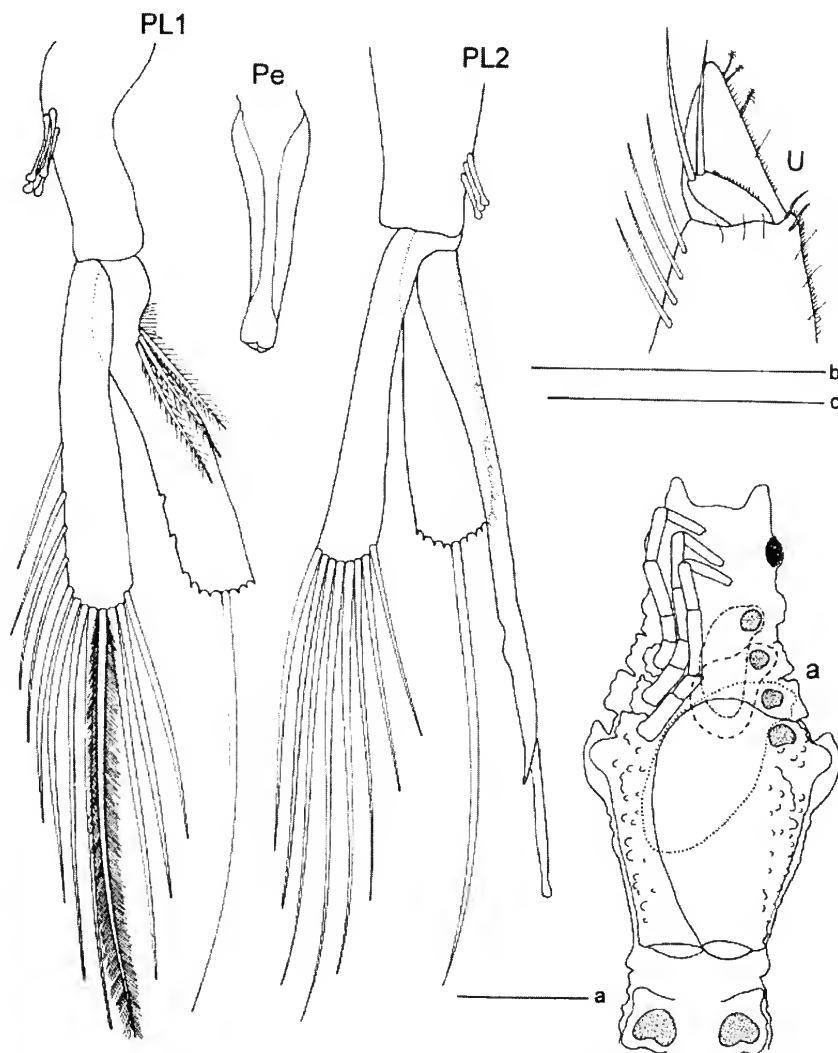


Figure 4 *Astacilla lewtonae* n.sp., male (NMV J16904): pleopods 1 and 2; penial plate. Female holotype (NMV J16900): distal end of uropod; a, ventral view with oostegites. Scales: a (PL1, PL2, Pe) = 0.5 mm; b (U) = 0.5 mm; c (e) = 1.0 mm.

Etymology

This species is named for Helen Lew Ton who detected this 'strange' species in the collections of Museum Victoria.

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The relationship between eastern and western populations of the Heath Rat, *Pseudomys shortridgei* (Rodentia: Muridae)

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The Heath Rat, *Pseudomys shortridgei* (Thomas, 1907), has a wide but disjunct range across southern Australia, occurring in heaths and shrublands in western Victoria, southern South Australia and Western Australia (Cockburn 1995). The holotype of *P. shortridgei* (Natural History Museum, London, no. 6.8.1.73) was collected by G.C. Shortridge on 27 Apr 1906 from Woylering, east of Pingelly, Western Australia (Tate 1951) (see Figure 1). Shortridge (1936) recorded the locality as "Woyaline Wells (source of the Avon River)". In Western Australia it is presently known only from Fitzgerald River National Park, Lake Magenta Reserve, Dragon Rocks Reserve, Hyden area and Ravensthorpe (specimens in the Western Australian Museum collection) (Figure 1). Two specimens were also accessioned into the Western Australian Museum collection in 1931 from the Lake Biddy area.

The distribution of *Pseudomys shortridgei* was much more extensive in southwestern Australia prior to European colonisation (Figure 1), ranging from the west coast of Shark Bay to the Great Australian Bight. Although this area encompasses six Interim Biogeographic Regionalisation of Australia regions (IBRA – Thackway and Creswell [1995]), varied habitat types and differing rainfall regimes, *P. shortridgei* is not recorded from all IBRA regions or habitat types within its former range (Figure 1).

The rediscovery of living populations of *Pseudomys shortridgei* in Western Australia was described by Baynes *et al.* (1987), and the species is currently listed as Declared Threatened Fauna in that State (Wildlife Conservation Notice 2001).

In eastern Australia, *Pseudomys shortridgei* now occurs almost exclusively in recently burnt, species-rich, treeless, dry heathlands in southeastern South Australia and southwestern Victoria (Cockburn 1995). It is dependent on post-fire regrowth (Cockburn *et al.* 1981) and the optimum situation for the species appears to be a mosaic of habitats of differing maturity, subject to disturbance by fire (Cockburn 1978). According to the Commonwealth of Australia (1999), the

species is classified as Mammals that are Vulnerable.

In a review of the fauna recorded from the Fitzgerald Biosphere Reserve, Chapman *et al.* (unpublished) compiled 77 records of this species (excluding the nine specimens in the Western Australian Museum collection). Vegetation of the sites varied, as did soil type. The predominant vegetation was shrub mallee over either heath or scrub over sedges. Sedges are thought to be an important dietary component (A. Sanders personal communication 2003). Some individuals were also trapped in shrublands on granites and low forest principally comprising *Eucalyptus gardneri ravensthorpensis*. Soils included loamy sands or sandy loams with a lateritic scree and clayey soils with a stony component. *Pseudomys shortridgei* has been recorded from a range of profiles on the landscape including a seasonally damp site low in the landscape and on top of a rocky ridge, about 40 metres high. Most records came from long unburnt vegetation (between 30 and 70 years) although Chapman *et al.* (unpublished) recorded five individuals from two sites in 2000 that had been previously burnt in November 1980. However, the apparent preference for long unburnt vegetation, which contrasts to eastern populations, may reflect a general paucity of trapping in recently burnt suitable habitat in Western Australia.

A survey by the Western Australian Museum along the coast of the Great Australian Bight in late summer 1984 failed to record *Pseudomys shortridgei* at Israelite Bay, Toolinna Cove, Eyre Bird Observatory or Eucla. Both Elliott and pitfall traplines were employed at all of these locations (R. How personal communication 2003). No *P. shortridgei* were trapped during the Nullarbor surveys in 1984 (Boscacci *et al.* 1987). These surveys suggest that the extant eastern and western populations of *P. shortridgei* are now disjunct, with a distance of about 1800 km between them.

The eastern and western populations have probably been separated for only a few thousand years. Surface remains from mainly coastal caves

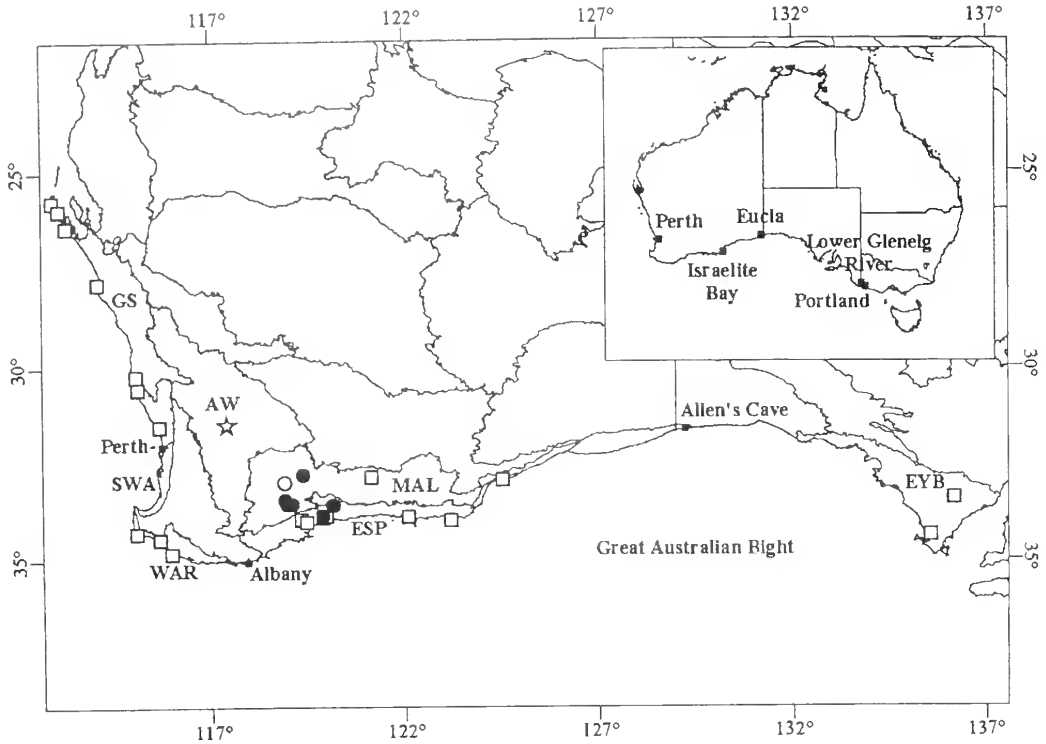


Figure 1 Map of southern Australia showing IBRA regions with former (open square), modern Western Australian Museum (pre 1983 open circles, post 1983 closed circles) locality records of *Pseudomys shortridgei*. The holotype, (collected 1906) is represented by a star. IBRA regions: AW, Avon Wheatbelt; ESP, Esperance Plains; EYB, Eyre Yorke Block; GS, Geraldton Sandplains; MAL, Mallee; SWA, Swan Coastal Plain; WAR, Warren.

(Baynes 1987) show that *Pseudomys shortridgei* occurred along the southern coast of Western Australia to at least the eastern end of the Wylie Scarp, on the western side of the Great Australian Bight, and on the Eyre Peninsula to the east, in immediately pre-European times (Figure 1). The species is also a component of the late Holocene fauna from Venus Bay near Ceduna (McDowell 1997) and is even sparsely recorded from the grey upper deposit in Allen's Cave, which lies near the eastern extremity of the mallee belt just east of the border between Western and South Australia. The grey upper deposit is of late Holocene age (Roberts *et al.* 1996). During the last Pleistocene glacial (oxygen isotope stages 2 and 3), sea-level was lower and the present Great Australian Bight was a sandy coastal plain up to 120 km wide (e.g. Bowler 1982). Fossil faunas (which include *P. shortridgei*) from both Devils Lair in southwestern Australia (Baynes *et al.* 1976; Balme *et al.* 1978) and Seton rock shelter on what is now Kangaroo Island (Hope *et al.* 1977), show that mammal communities in southern coastal areas during the last glacial had greater species-richness than those of the Holocene interglacial, probably because glacial climates were less

seasonal. All these points suggest that there was a continuous population of *P. shortridgei* along the central southern coast of Australia during much if not all of the last glacial.

Several other mammal taxa which also inhabit shrub formations and that are currently judged to be the same species on both sides of the Bight, shared this original distribution pattern: *Parantechinus apicalis*, *Isodon obesulus*, *Potorous platyops*, *Macropus eugenii*, *Cercartetus concinnus*, *Pseudomys occidentalis* and *Rattus fuscipes* (Baynes 1987; distribution maps in Strahan 1995). *Notomys mitchellii* had a similar though continuous distribution in immediately pre-European times. In contrast, neither *Pseudomys albocinerens* nor *P. apodemoides* has been recorded from either Eyre Peninsula or Kangaroo Island, even as a fossil. These two species were synonymised by Ride (1970), and have been assumed to be a 'sibling pair' (but see below).

From recent survey work in Western Australia, in areas where *Pseudomys shortridgei* is known to be extant, few individuals have been trapped. From 4460 Elliott trap-nights (medium size Elliott traps) and 1494 pitfall trap-nights within the Fitzgerald

Biosphere Reserve between 1993 and 2001, just 77 capture events were recorded from 11 sites. This is much less than the 708 capture events of the Bush Rat, *Rattus fuscipes* across 47 sites during the same studies (Chapman *et al.* unpublished). In Victoria, Happold (1976) and Braithwaite (1977) found that the density of animals in favoured areas was six per hectare and that numbers did not vary temporally.

Before there is further work to study the size, extent and status of the populations of *Pseudomys shortridgei* in Western Australia, it is important to know whether the well-studied eastern populations belong to the same species as the populations in Western Australia. If they are different species, then information on the biology of the eastern populations may not be suitable as a basis for management in Western Australia. There have been no previously published morphological or molecular genetic studies to examine if the two populations are indeed the same species. The first step in the evaluation of the taxonomic status of the western and eastern populations has been the molecular genetic analysis of tissues from eastern and western specimens.

We nucleotide sequenced approximately 300 base pairs of the mitochondrial *cytochrome b* gene by polymerase chain reaction amplification and direct sequencing using the primers H15149 and L14841 (Kocher *et al.* 1989). Specimens used in this study are listed in Table 1. An evolutionary tree of the aligned sequences constructed with the Neighbour-Joining algorithm from Kimura 2-parameter distances showed that there is a split between the Western Australian and eastern states samples (two only of the latter) at about 2.6% sequence divergence on average (Table 2). This level of divergence is less than that seen between species of *Pseudomys*, for instance distances between species of pebble-mound mice exceed 5.6% uncorrected sequence divergence and the distance between the east-west 'sibling' species *Pseudomys albocinereus*

Table 1 Collection data for specimens used in molecular analysis. Prefixes for registration numbers are WAMM – Western Australian Museum mammal collection; ABTC – Australian Biological Tissue Collection, South Australian Museum.

Western Australia	
Fitzgerald River National Park, 33°52'08"S, 119°54'12"E, WAMM26644; Lake Magenta Reserve, 33°35'00"S, 118°58'00"E, WAMM41908, WAMM49272-3; Lake Magenta Reserve, 33°28'01"S, 118°55'01"E, WAMM52338	
South Australia	
Lower Glenelg River CP, 38°00'00"S, 140°57'00"E, ABTC79270	
Victoria	
6 km W Portland, 38°20'00"S, 141°32'00"E, ABTC8079	

Table 2 Distance matrix of uncorrected genetic distances (percentages) of partial mitochondrial *cytochrome b* sequences for *Pseudomys shortridgei*

	1	2	3	4	5	6	7
1 ABTC8079	–						
2 ABTC79270	0.000	–					
3 WAMM26644	0.026	0.026	–				
4 WAMM41908	0.026	0.026	0.000	–			
5 WAMM49272	0.026	0.026	0.000	0.000	–		
6 WAMM49273	0.026	0.026	0.007	0.007	0.007	–	
7 WAMM52338	0.026	0.026	0.000	0.000	0.000	0.007	–

and *P. apodemoides* is 12% for the same sequence. However, mitochondrial DNA analyses (Torrance and Donnellan unpublished observations) suggest that *Pseudomys albocinereus* and *P. apodemoides* are not sister taxa. There is minor divergence (0.7%) between individuals of *P. shortridgei* in the Lake Magenta area in Western Australia and no divergence between the two eastern states samples.

Taken together, the data on historical distribution, ecology and genetic divergence suggest recent separation of eastern and western *Pseudomys shortridgei* populations and support the present treatment of those populations as a single species. The level of molecular divergence between Western Australian and South Australian and Victorian samples is low compared with differences among sibling species of *Pseudomys*, and furthermore the reciprocal monophyly of the eastern and western mitochondrial lineages (if indeed this still holds up with a larger number of individuals sampled) could have arisen quickly following a rapid diminution in range and consequent population decline following the last glacial just a few thousand years ago. That the western and eastern populations appear to occupy different habitats may simply reflect the lack of identical habitats in the two widely separated regions. It would be desirable to confirm the status of the populations with a morphological study.

ACKNOWLEDGEMENTS

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Guide to Authors

Subject Matter:

Reviews, observations and results of research into all branches of natural science and human studies will be considered for publication. However, emphasis is placed on studies pertaining to Western Australia. Longer papers will be considered for publication as a Supplement to the *Records of the Western Australian Museum*. Short communications should not normally exceed three typed pages and this category of paper is intended to accommodate observations, results or new records of *significance*, that otherwise might not get into the literature, or for which there is a particular urgency for publication. All material must be original and not have been published elsewhere.

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Authors are advised to follow the layout and style in the most recent issue of the *Records of the Western Australian Museum* including headings, tables, illustrations and references.

The title should be concise, informative and contain key words necessary for retrieval by modern searching techniques. An abridged title (not exceeding 50 letter spaces) should be included for use as a running head.

An abstract must be given in full length papers but not short communications, summarizing the scope of the work and principal findings. It should normally not exceed 2% of the paper and should be suitable for reprinting in reference periodicals.

The International System of units should be used.

Numbers should be spelled out from one to nine in descriptive text; figures used for 10 or more. For associated groups, figures should be used consistently, e.g. 5 to 10, not five to 10.

Spelling should follow the *Concise Oxford Dictionary*.

Systematic papers must conform with the International Codes of Botanical and Zoological Nomenclature and, as far as possible, with their recommendations.

Synonymies should be given in the short form (taxon, author, date, page) and the full reference cited at the end of the paper. All citations, including those associated with scientific names, must be included in the references.

Manuscripts:

The original and two copies of manuscripts and figures should be submitted to the Editors, c/- Publications Department, Western Australian Museum, Francis Street, Perth, Western Australia 6000. They must be in double-spaced typescript on A4 sheets. All margins should be at least 30 mm wide. Tables plus heading and legends to illustrations should be typed on separate pages. The desired position for insertion of tables and illustrations in the text should be indicated in pencil. Tables should be numbered consecutively, have headings which make them understandable without reference to the text, and be referred to in the text.

High quality illustrations are required to size (16.8 cm x 25.2 cm) or no larger than 32 cm x 40 cm with sans serif lettering suitable for reduction to size. Photographs must be good quality black and white prints, not exceeding 16.8 cm x 25.2 cm. Scale must be indicated on illustrations. All maps, line drawings, photographs and graphs, should be numbered in sequence and referred to as Figure/s in the text and captions. Each must have a brief, fully explanatory caption. On acceptance a computer disk containing all corrections should be sent with amended manuscript. The disk should be marked with program (e.g. Word, WordPerfect, etc).

In papers dealing with historical subjects references may be cited as footnotes. In all other papers references must be cited in the text by author and date and all must be listed alphabetically at the end of the paper. The names of journals are to be given in full.

Processing:

Papers and short communications are reviewed by at least two referees and acceptance or rejection is then decided by the editors.

The senior author is sent one set of page proofs which must be returned promptly.

The senior author will receive fifty free offprints of the paper. Additional offprints can be ordered at page proof stage.

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